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MATERIALS BALANCE AND TECHNOLOGY ASSESSMENT OF MERCURY AND ITS COMPOUNDS ON NATIONAL AND REGIONAL BASES

URS Research Company

PREPARED FOR
Environmental Protection Agency

October 1975

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Materials Balance and Technology Assessment of Mercury and Its Compounds on National and Regional Bases

October 1975
Final Report

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Toxic Substances
Washington, D.C. 20460

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The role of mercury and its compounds in the environment and the economy of the United States was studied. A detailed material balance for mercury and its compounds was developed on a national basis and for selected geographical regions, including estimates of the environmental fate of all emissions.

Current and projected process technologies for mercury products were examined, and estimates of environmental losses for 1973 and 1983 were presented. A set of regulatory alternatives was developed for each of the major technologies involving substantial losses of mercury to the environment, and the economic impact of these alternatives was examined.

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Mercury
Mercury Compounds
Mercury Production
Mercury Compounds Production
Mercury Use
Mercury Compounds Use
Mercury Control Technology
Substitutes for Mercury

Mercury in Air
Mercury in Water
Mercury in Land-Destined Wastes
Mercury in Batteries
Mercury in Electrical Equipment
Mercury in Chlor-Alkali Industry
Mercury in Dentistry
Mercury in Fossil Fuels
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MATERIALS BALANCE AND TECHNOLOGY ASSESSMENT OF MERCURY AND ITS COMPOUNDS ON NATIONAL AND REGIONAL BASES

October 1975

Final Report
Contract 68-01-2930

Project Officer
David Garrett, P.E.

Prepared for
Environmental Protection Agency
Office of Toxic Substances
Washington, D.C. 20460

PREFACE

This study was conducted under Contract 68-01-2930 for the Office of Toxic Substances (OTS), Environmental Protection Agency, Washington, D.C. Mr. David Garrett was the EPA Project Officer. Mr. Garrett and Dr. Herbert Katz of OTS were most helpful in providing guidance and assistance during the course of the study. Other branches of the Agency were also cooperative in providing advice and information on studies and data sources used in the study. Representatives of various industries were contacted for information, and many were most generous in providing insights and data regarding their industries and technologies. To all of these who contributed to this project, we express our thanks.

This work was conducted in the Hazards Assessment Directorate of URS Research Company, under the administrative direction of William H. Van Horn, who also served as project manager. Other URS personnel who contributed technical inputs to the report include Dr. Wesley Bradford, Leon Crain, Charles Hamman, Gary Kaufman, Lance Johnson, Michael LaGraff, Eric Schrier, Ruth Shnider, and William Penn. Research, editorial, and typing support was provided by Margaret Chatham, Marna Lieberman, Frances Maurier, Lucy Vincent, and Louise Zwick.

The study covers a very broad spectrum of disciplines, and information was obtained from many published and unpublished sources, as well as numerous proprietary contacts. While the authors have attempted to minimize errors, the type and magnitude of the study mean that some errors have undoubtedly crept into the report. We assume responsibility for such inadvertent mistakes and will attempt to correct important deficiencies upon receipt of better data.

CONTENTS

Section Page

EXECUTIVE SUMMARY . . . . a

Purpose of Study . . . . a
Method of Approach . . . . a
Uses of Mercury . . . . a
Study Results . . . . b
Technology Assessment . . . . e
Regulatory Impacts i
Conclusions . . . . j
Findings . . . . m

I INTRODUCTION 1

Scope of Work 5
Method of Approach 6
Report Organization 9

II HISTORICAL OVERVIEW AND OUTLOOK SUMMARY 11

Sources of Mercury 11
Present and Projected Mercury Consumption 11
Major End Uses 15
  Agriculture 15
  Catalysts 15
  Dental Preparations 15
  Electrical Apparatus 16
  Caustic-Chlorine (Chlor-Alkali) 16
  Paints 17
  Pharmaceuticals 17
  Other Uses (including Laboratories) 18
  Consumption by Federal Agencies 18
Regional Distribution 18
Final Disposal 20
Ultimate Fate of Mercury in the Environment 25
Legislation and Regulations Applicable to Mercury 29
  Mercury Crisis: The Early Response 29
  Regulatory Guidelines and Actions 31
    The Air Environment 31
    The Land Environment 31
    The Water Environment 31
  Interstate Transportation 33
  Trends in Legislation and Regulatory Action 33

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CONTENTS
(continued)

Section		Page
III	INPUT/OUTPUT ANALYSIS	37
	Introduction	37
	Methodology	38
	Development of an Input/Output Model	42
	Acquisition of the Data	48
	Calculation of Contributions from Natural Sources . .	54
	Degassing	54
	Runoff	58
	Contributions from Final Disposal	58
	Sewage	58
	Groundwater	60
	Results	60
	Regional Analyses	62
	California Study Region	62
	Arizona Study Region	65
	Kentucky/Tennessee Study Region	67
	Louisiana Study Region	73
	New York/New Jersey Study Region	75
	National Inventory	79
	Risk Analysis	91
	Selection of Technologies for Study	98
IV	TECHNOLOGY ASSESSMENT	105
	Introduction	105
	Microtechnologies	107
	Sector I - Mercury Input	107
	Mercury Mining and Refining	107
	Sector II - Mining	116
	Copper Mining and Smelting	116
	Sector III - Miscellaneous Unregulated Sources . . .	128
	Power Plants	128
	Sector V - Manufacturing and Processing	138
	Chlor-Alkali Manufacturing	138
	Manufacture of Mercurials	153
	Battery Manufacturing	170
	Electric Lamp Manufacturing	178
	Industrial Instruments	185
	Paint Manufacturing.	195
	Sector VIII - Commercial and Final Consumption . . .	205
	Agricultural Pesticides	205
	Nonagricultural Pesticdes	212
	Laboratory Uses	217

CONTENTS
(continued)

Section		Page
IV	TECHNOLOGY ASSESSMENT (Cont.)	
	Sector VIII - Personally Oriented Final Consumption	222
	Dental Applications	222
	Pharmaceuticals	227
	Final Disposal Sector	230
	Municipal Waste Treatment	230
	Municipal Solid Waste Disposal	237
	Macrotechnology	246
	Implications	246
V	REGULATORY IMPACT ANALYSIS	253
	Introduction	253
	Methodology	255
	Regulation in the Chlor-Alkali Industry	257
	Alternative I--Elimination of Substitution of Product	257
	Alternative 2--Alternate Technologies	258
	Alternative 3--Increased Control	261
	Introduction of New Emission Control Technology . .	263
	Cost-Benefit Analysis	267
	Risk Analysis	269
	Regulation in the Paint Industry	271
	Regulatory Alternatives and Effects	272
	Cost-Benefit Analysis	280
	Risk Assessment	280
	Regulation in the Battery Industry	282
	Industry Regulation	284
	Cost-Benefit Analysis	289
	Risk Assessment	292
	Overview	292
	REFERENCES	
	APPENDIXES	
	A. Mercury in the Environment	
	B. Selection of Study Regions	
	C. Computer Data Base Format and Use	
	D. General Methodology	
	E. Point Source Emissions of Mercury	

FIGURES

Number		Page
A	Percent Distribution of Consumptive Uses of Mercury, 1973	e
B1	Percent Distribution of Estimated Emissions to Air of Mercury from Man-Related Sources, 1973	b
B2	Percent Distribution of Estimated Emissions to Water of Mercury from Man-Related Emissions, 1973	f
C	Annual Emissions of Mercury to the Environment from Man-Related and Natural Sources	g
1	Study Regions	8
2	Projected Mercury Consumption in the United States, by End Use	14
3	Past and Probable Future Trends in Final Disposal of Mercurials	22
4	Mercury Cycling through Environmental "Reservoirs" . .	27
5	Variations in Mercury Content of the Environment in Relation to Existing Standards	28
6	Sources of Mercury and Industrial and Commercial Usage in the United States, 1973	39
7	Basic Mercury Inventory Flow Chart	43
8	Materials Balance of Mercury from Coal in the United States	52
9	Mineralized Areas and Mercury Deposits in the United States	59
10	Mercury Emissions to Land in Kentucky/Tennessee Study Region, by County, 1973	70
11	Mercury Emissions to Air in Kentucky/Tennessee Study Region, by County, 1973	71
12	Latitude/Longitude Analysis of Mercury Emissions along Tennessee River, Kentucky/Tennessee Study Region, 1973	72
13	Mercury Emissions to Air in New York/New Jersey Study Region, by County, 1973	78
14	Mercury Emissions to Water in New York/New Jersey Study Region, by County, 1973	80

FIGURES
(Continued)

Number		Page
15	Mercury Emissions to Land in New York/New Jersey Study Region, by County, 1973	81
16	Latitude/Longitude Analysis Areas in New York/ New Jersey Study Region	82
17	Annual Elevated Mercury Losses to Air	92
18	Annual Elevated Mercury Losses to Water	93
19	Annual Elevated Mercury Losses to Land	94
20	Mercury Emissions as a Function of Population Density	95
21	Summary of Mercury Losses to the U.S. Environment by Sector and Class, 1973	99
22	Flow Diagram of Mercury Recovery Using 1973 Technology	111
23	Mercury Recovery Using 1983 Technology	113
24	1973 Technology for Copper Mining and Smelting . . .	119
25	1983 Technology for Copper Mining and Smelting . . .	122
26	Maximum Mercury Vapor Concentrations for Cases 1-4 .	126
27	Mercury Losses from Typical Power Plants, 1973 . . .	133
28	Mercury Losses from Typical Power Plants, 1983 . . .	135
29	Mercury Losses from a Typical Chlor-Alkali Manufacturing Plant, 1973	143
30	Mercury Losses from a Typical Chlor-Alkali Manufacturing Plant, 1983	148
31	Mercury Balance for the Preparation of Mercuric Sulfide and Mercuric Chloride	159
32	Mercury Balance for Two Methods for Production of Red Mercuric Oxide	160
33	Mercury Balance for Synthesis of Phenylmercuric Acetate	161
34	Wastewater Flow in a Plant Producing Mercurials and Nonmercurials	163

FIGURES
(Continued)

Number		Page
35	Manufacturing Process for Vinyl Chloride Monomer Using a Mercury Catalyst	164
36	Mercury Loss in Manufacturing, by Type of Battery, 1973	171
37	Flow Diagram of Mercury Losses during Manufacture of Ruben Mercury Cell Batteries	175
38	Flow Diagram of Estimated Mercury Losses during Manufacture of Fluorescent Lamps	183
39	Flow Diagram of Mercury Losses in Typical Control Instrument Manufacturing Process	191
40	Flow Diagram of Mercury Losses in Typical Switch and Relay Manufacturing Process	192
41	Flow Diagram of Estimated Mercury Losses in Typical Paint Manufacturing Operation in 1973 . . .	201
42	Flow Diagram of Estimated Mercury Losses from Typical Paint Manufacturing Operations in 1983 . .	201
43	Mercury Balance, Agricultural Pesticide Manufacture and Use, 1973 Technology	209
44	Mercury Balance, Nonagricultural Pesticide Manufacture and Use, 1973 Technology	214
45	Mercury Losses from Laboratory Usage, 1973	219
46	Mercury Losses from Laboratory Usage, 1983	219
47	Mercury Balance, Dental Applications, 1973 Technology	223
48	Mercury Balance, Dental Applications, 1983 Technology	225
49	Mercury Balance, Pharmaceuticals Manufacture and Use, 1973 Technology	229
50	Path of Mercury in a 100 MGD Sewage Treatment Plant	235
51	Flow of Mercury in the Municipal Solid Waste Stream of a Typical Community of 500,000 in 1973	242

FIGURES
(Continued)

Number		Page
52	Flow of Mercury in the Municipal Solid Waste Stream of a Typical Community of 500,000 in 1983 .	243
53	Sequential Mercury Losses in Electrical Applications, 1973	248
54	Sequential Mercury Losses in Paint Applications, 1973	249
55	Rate of Introduction of Pollution Control Technology	264
56	Time-Phased Reduction of Mercury Emissions from Mercury Cell Chlor-Alkali Plants, and Associated Costs	268
57	Product and Income Flow for the Production and Consumption of Mercury-Containing Paints	273
58	Price Elasticity of Demand in the Paint Industry . . .	276
59	Consumer and Manufacturing Costs Associated with the Removal of Mercury from Paint	279
60	Time-Phased Reduction in Mercury Losses from Paint Usage, and Associated Costs	281
61	Product and Income Flow for the Production and Consumption of Mercury-Containing Batteries	283
62	Time-Phased Reduction in Mercury Losses from Battery Recycling, and Associated Costs	290

TABLES

Number		Page
A	Comparison of Regional and National Inventory Results .	d
1	Mercury Consumption in the United States, 1965-1973, by End Use	13
2	Sales of Manufactured Products Containing Mercury . . .	19
3	EPA Mercury Regulations	32
4.	Input/Output Model Sectors	44
5	Inputs into the Input/Output Inventory	47
6	Outputs from Various Programs in the Input/Output Model	49
7	Emissions and Emission Factors for Mercury, by SIC and Sector	55
8	Natural Degassing Rates Calculated by Various Workers	57
9	Mercury Emissions to the Environment in the California Study Region	63
10	Mercury Emissions to the Environment in the Arizona Study Region	66
11	Mercury Emissions to the Environment in the Kentucky/Tennessee Study Region	68
12	Mercury Emissions to the Environment in the Louisiana Study Region	74
13	Mercury Emissions to the Environment in the New York/New Jersey Study Region	76
14	Per Capita Distribution of Mercury Losses to Air, Land, and Water in Five Areas of New York/New Jersey Study Region	83
15	Total Mercury Losses in 1973 for the Coterminous United States, by Sector and SIC Category	84
16	Total Mercury Losses in 1973 for the Coterminous United States, by State	86
17	Comparison of Regional and National Inventory Results	90
18	Production of U.S. Mercury Mines in 1973	109

TABLES
(continued)

Number		Page
19	Estimated Total Production and Mercury Emissions from Mercury Mining and Refining: 1973 and 1983 . .	115
20	Estimated U.S. Smelter Production of Copper, 1973 .	118
21	Estimated Emissions from Copper Smelting, 1973 and 1983	124
22	Power Plant Mercury Losses in the United States, 1972	130
23	United States Chlor-Alkali Manufacturers and Estimated Mercury Losses of Plants, by State, 1973 . . .	141
24	Materials Balance for Chlor-Alkali Plant, 1973 . . .	145
25	Materials Balance for Chlor-Alkali Plant, 1983 . . .	149
26	Estimated Mercury Losses from Typical Chlor-Alkali Plant Operations, 1973 and 1983	152
27	Estimated Mercury Consumption of Mercurials in 1973, by Plant and Product End Use Category	155
28	Estimated Mercury Losses from Production of Mercurials, 1973 and 1983	169
29	Estimated Mercury Losses from Use of Manufactured Catalysts in the Production of Vinyl Chloride Monomer and Vat Dyes	169
30	Major U.S. Battery Manufacturers' Mercury Losses by Plants and State, 1973	173
31	Estimated U.S. Battery Manufacturing and Related Consumer Losses of Mercury, 1973 and 1983	177
32	Estimated Mercury Losses from Electric Lamp Manufacturing in the United States, by State, 1973	180
33	Estimated Mercury Losses from Lamp Manufacturing and Use, 1973 and 1983	184
34	Estimated Mercury Losses from Industrial Instrument Manufacturing, by State, 1973	187
35	Estimated Mercury Losses from Industrial Instrument Manufacture and Use, 1973 and 1983	194

TABLES
(Continued)

Number		Page
36	Mercury Losses from U.S. Paint Manufacturing Operations, by State, 1973	197
37	Estimated Mercury Losses from Paint Manufacture and Use, 1973 and 1983	204
38	Regional Distribution of Industrial Wastewater Discharges to Community Sewers in 1968	232
39	Wastewater Discharges to Community Sewers in 1968, by Industrial Category	233
40	Estimated Mercury Emissions from U.S. Municipal Sewage Treatment Plants, 1973 and 1983	238
41	National Solid Waste Disposal Practices	239
42	Estimated Mercury Losses to Environment from U.S. Municipal Solid Waste Disposal, 1973 and 1983	245
43	Mercury Losses for Various Applications, 1973	247
44	Emission Control Technology for Mercury Cell Chlor-Alkali Industry: Estimated Annual Cost and Emissions, 1973-1983	265
45	Estimated Product and Income Flow for Production and Consumption of Paints Containing Mercury, 1973 . . .	275
46	Estimated Income and Employment Consequences of a Shift to Substitutes for Mercury in Paint Manufacture and Use	278
47	Estimated Product and Income Flow for Production and Consumption of Batteries Containing Mercury, 1973-1983	286

EXECUTIVE SUMMARY

PURPOSE OF THE STUDY

The toxic nature of mercury and its compounds and the relative ease with which these materials may, when improperly discharged to the environment, enter into man's food chain and affect him adversely have been recognized only in recent years. Our understanding of mercury's transfer mechanisms within nature and of its adverse effects on man is still limited. Little reliable data are available on quantities of mercury in the environment and it is difficult to assess whether mercury may actually be building up in the biosphere. The Office of Toxic Substances of the Environmental Protection Agency has funded this study, recognizing that more definitive data are needed concerning the amount of mercury entering the environment each year and on the manner in which this mercury is redistributed (particularly with regard to introduction into man's food chain). The Agency also wishes to determine what requirements there may be for regulatory actions to reduce unnecessary or unsafe discharges of mercury to the environment.

METHOD OF APPROACH

Quantitative data are generally not available to pinpoint the locations of mercury in the environment (whether it be in air, water, or land), Therefore, URS Research Company used a study approach which traced all sources of introduction of mercury and its compounds into the environment and then determined where losses were incurred. This input/output study required that all mercury sources be identified and that the mercury be traced through usage to final disposition for each source. Five U.S. regions were selected, each having some unique characteristics with respect to usage of mercury, and an inventory was made of mercury usage in these regions. A similar inventory was made for the nation, and the regional and national results were compared. The data base was very large, so a computer-based inventory model was developed. The regional and national inventories formed the basis for assessing which were the most important sources of discharges of mercury to the environment. An additional study was then made of the technology involved with respect to these identified emitters, and forecasts of possible future trends were developed. Finally, three technologies were selected for evaluation of the economic impact of regulatory actions with respect to mercury.

USES OF MERCURY

Mercury and its compounds are used in relatively small quantities (partially because of their high cost), but the uses are distinctive and varied. Mercury metal is the only common liquid metal; because of its conductive characteristics it has many specialized electrical applications. Many mercury compounds are chemically and biologically active and are uniquely useful as chemical reagents and biological pesticides and preservatives. Figure A shows major uses for mercury and its compounds in 1973. The ways in which the slightly less than 1,900 tonnes* were used by industry and commerce, and the resultant emissions, are a major concern in this report. The use of mercury has been declining in recent years both because of the concern over its possible hazards and because of its cost (currently about $4 per pound). Production of mercury in this country has been particularly hard hit because of control technology requirements and depressed prices. Some industries -- notably paper and gold mining -- formerly used mercury or mercury compounds but no longer do so, primarily because of the recognized hazards of the materials.

Mercury also comes from some "unregulated sources" such as power plants and livestock manure. Mercury occurs in many natural materials, and fossil fuels are among these sources. Coal in particular is high in mercury (although we are talking about perhaps one part of mercury for every million parts of coal). With the increasing use of coal as a power source, mercury emissions -- primarily to air -- are likely to increase.

Mercury is present in trace amounts in virtually all soils, and these soils release mercury vapor to the air in trace amounts (the so called "degassing" phenomenon); over a large land mass this degassing effect accounts for large amounts of mercury.

Mercury and its compounds are notorious for moving from one medium to another. Thus mercury compounds discharged to a water stream may settle as insoluble compounds in the sediments, there to be acted upon by bacterial action ("methylation"), forming soluble toxic mercury compounds which have been demonstrated to enter man's food chain via fish. Although these compounds generally enter the chain in small quantities, they are undeniably toxic; hence we must always be concerned with the ultimate fate of mercury.

STUDY RESULTS

Most of the mercury consumed each year eventually reaches the environment. A summary of the findings of the regional and national inventories is given in Table A for major man-related sources of emissions. It can be seen that the study regions deviate, sometimes markedly, from national values; these deviations are related to specific, known sources of mercury emissions. For example, copper mining in Arizona causes the high emissions value for "other mining." Chlor-alkali manufacturing (for the production of chlorine) accounts for the high "manufacturing" loss in the Louisiana study region. Certainly of interest are the high mercury losses accounted

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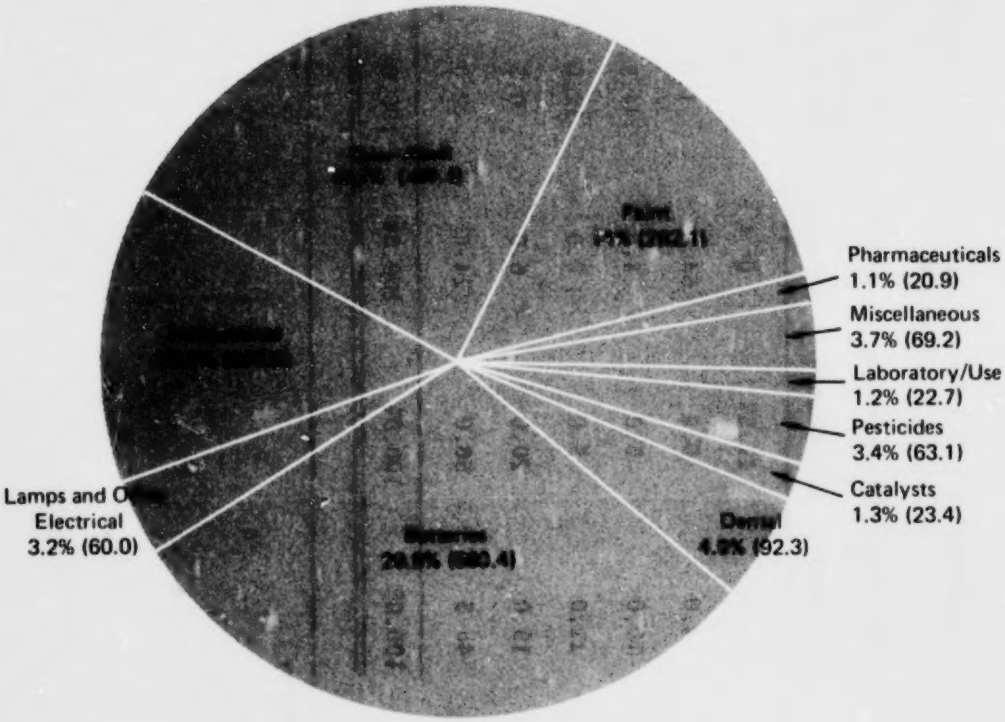
* The (metric) tonne is about 10 percent heavier than the short ton of 2,000 pounds. One tonne contains 1,000 kilograms (kg), or 2,205 pounds.



SOURCE: URS Research Company.

Figure A PERCENT DISTRIBUTION OF CONSUMPTIVE USES OF MERCURY, 1973 (Tonnes)

TABLE A. - Comparison of Regional and National Inventory Results
(percent)

Sector Name	National	California	Arizona	Kentucky/ Tennessee	Louisiana	New York/ New Jersey
Mercury Mining	0.5%	11.5%	0 %	0 %	0%	0%
Other Mining	4.0	0.5	64.0	1.0	0	0
Unregulated Sources	10.0	5.0	4.0	44.5	5	21
Manufacturing	21.0	5.0	2.0	12.0	71	7
Industrial Consumption	19.0	20.0	6.0	0.5	5	6
Personal Consumption	45.5	58.0	24.0	42.0	19	66
Total	100.0%	100.0%	100.0%	100.0%	100 %	100 %

Source: URS Research Company

for by the final consumption of mercury-containing products, both by industry and individual consumers (for instance, batteries, dental fillings). The high aggregate losses at the consumer level create special control problems, since they are made up of many small losses by many persons and users.

We are concerned not only with size of the losses but also with points of loss. Mercury wastes directed to regulated landfills, which do not leach to groundwaters, are of less concern than are discharges to air or to water, which are more directly accessible to man and his food chain. (It should be noted, however, that two-thirds of all solid wastes are disposed of in unregulated sites, for which data are lacking.) Figure B shows estimated 1973 losses of mercury and its compounds to these two reservoirs--air and water--from man-related applications or uses.

The man-related emissions must be viewed in the perspective of all mercury emissions. Figure C shows all mercury emissions to air, water, and land from both man-related and natural sources. Emissions from natural sources, which are difficult to estimate, appear to outweigh man-related emissions. However, these natural sources are relatively uniformly distributed and do not concentrate specifically in man's habitat. Man-related discharges, on the other hand, concentrate in population centers, and a direct relationship between total mercury discharges and total population can be demonstrated. We found that, aside from industrial and mining applications, as a rule of thumb the estimated emissions* of mercury on a per capita basis are: air, 1.80 g; water, 0.39 g; land, 4.25 g. It is noteworthy that the emissions to water are by far the lowest on a per capita basis. This indicates that ongoing practices have been quite successful in reducing these discharges.

TECHNOLOGY ASSESSMENT

The report considers in some detail current (1973) and forecast (1983) technologies which may affect the rate of mercury discharge to the environment. The technology assessment identifies production sites (where appropriate), the point of discharge, alternatives which might be employed to reduce reliance on mercury, and estimated total discharges in 1973 and 1983. Some highlights of the findings are summarized below:

- Mercury mining may increase sharply but improved technology will prevent concurrent rises in emissions.
- By adopting available technology, copper smelters can reclaim appreciable quantities of mercury and reduce the environmental burden from smelting.
- Manufacturers of chlorine who use the mercury cell process can, by applying available technology, reclaim much of the mercury that is currently lost (primarily to land). By 1983 more than 75 percent of the mercury used in this process can be reclaimed.

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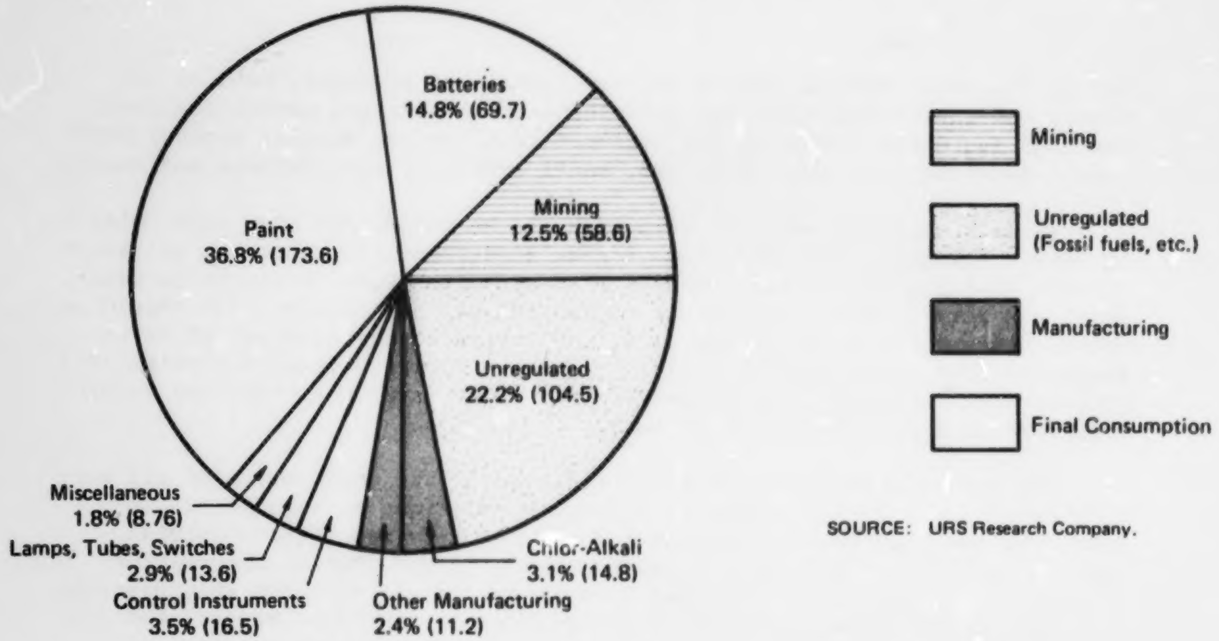
* In grams (g); 28 grams = 1 ounce.



SOURCE: URS Research Company.

Figure B-1 PERCENT DISTRIBUTION OF ESTIMATED EMISSIONS TO AIR OF MERCURY FROM MAN-RELATED SOURCES, 1973 (Tonnes)

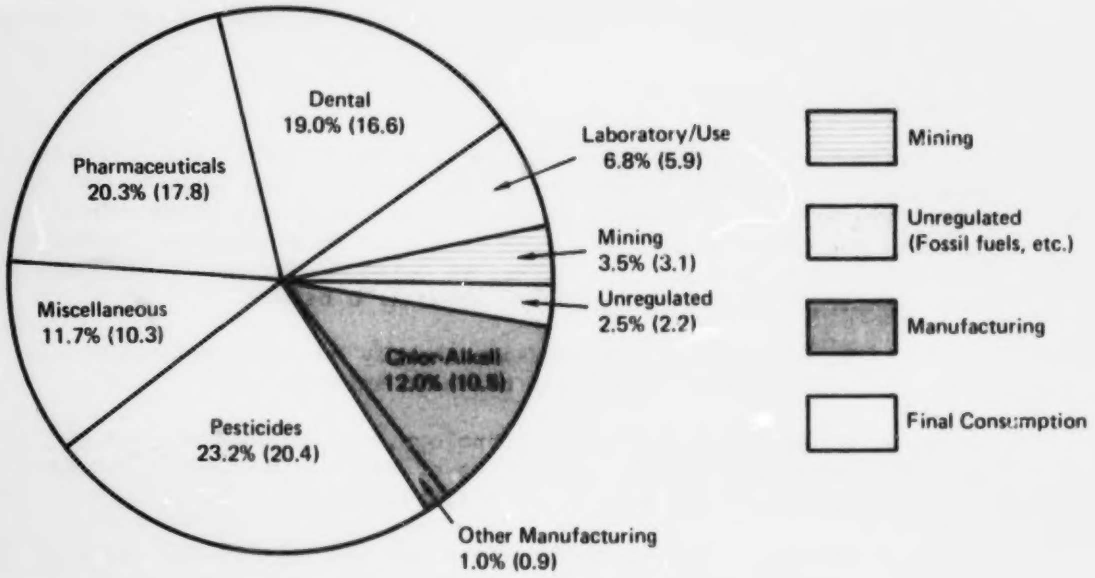


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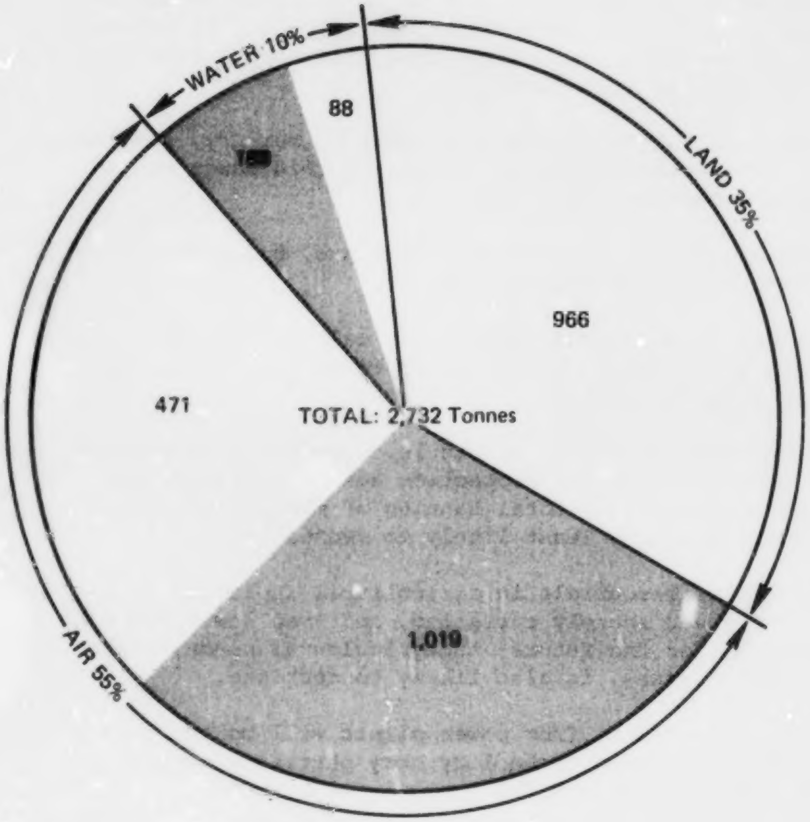
Figure B-2 PERCENT DISTRIBUTION OF ESTIMATED EMISSIONS TO WATER OF MERCURY FROM MAN-RELATED SOURCES, 1973 (Tonnes)



☐ Man-Related Emissions

▨ Natural Emissions

SOURCE: URS Research Company.

Figure C ANNUAL EMISSIONS OF MERCURY TO THE ENVIRONMENT FROM MAN-RELATED AND NATURAL SOURCES (Tonnes)

- Manufacturers of mercury compounds are currently minor sources of emissions and will become even less important in future years.

- The battery industry -- one of the largest consumers of mercury -- is likely to grow in the future; unless the current rate of 5 percent mercury recycling is substantially increased, emissions from this source will continue to rise appreciably.

- Lamps are fairly substantial users of mercury, and there is little possibility of decreasing this usage by recycling mercury from lamps.

- Dental usage of mercury will continue, but unnecessary losses will be sharply curtailed.

- The use of mercury in pharmaceuticals is declining, but there will continue to be some demand for mercury for unique applications.

- The use of mercury in paints is currently under attack by the Environmental Protection Agency; even if this does not result in total banning of mercury in paint, such usage is at least likely to decrease.

- The use of mercurials in agricultural applications has already been sharply curtailed, and even lower usage is forecast for the future; nonagricultural usage, primarily on golf courses, is also likely to decrease.

- Mercury emissions from power plants will continue to grow, and present technology only partially removes mercury from stack gases.

- Sewage plants receive wastes containing mercury from both natural and man-related sources, concentrate a portion of this mercury in the sludge, and discharge the remainder to the receiving waters. If the sludge is burned, mercury is released to the air; if the sludge is used as a soil additive, mercury (and other heavy toxic metals) may build up to dangerous levels.

- Of the solid wastes generated in this nation, an average of about 92 percent are disposed of in landfills and about 8 percent are incinerated. The trend is toward greater material and energy recovery, with an attendant decrease in waste volume. Greater energy recovery could result in more emissions to air, but increased material recovery can be designed to decrease mercury emissions through the segregation and removal of mercury-containing wastes.

The control of mercury emissions is most feasible at the manufacturing or processing level. For this reason control at this point has progressed ahead of controls for mercury losses from other sources of emissions. Continuing attempts to reduce mercury emissions at all points of their entry into the environment are desirable. (Of course, natural emissions, although large, are not controllable; however, because of their diffuse nature they are of less concern than the man-related emissions that collect where man congregates.)

REGULATORY IMPACTS

An analysis was made of several alternatives that might be imposed by regulatory action, and of the economic impacts of such alternatives. The alternatives, designed to reduce or eliminate mercury emissions, include the use of a substitute product or an alternative technology that does not require mercury or its compounds; improved emission controls (which may allow reclamation of mercury); and recyling of mercury from mercury-containing products. Three case studies were considered: the chlor-alkali manufacturing industry; latex paint manufacture and consumption; and battery manufacture and consumption.

The portion of the chlor-alkali industry that uses mercury cells, although growing, is resisting attempts to convert to other technologies that do not use mercury -- namely the diaphragm cell. Although the two technologies are competitive, the conversion costs are at the present time excessively high. The cost of converting the 28 existing mercury cell plants in this country to the diaphragm technology, over the ten-year period 1973-1983, would be roughly $600 million but would result in a 100-percent reduction of mercury emissions (up to 326 tonnes annually). However, at a cost of a little over $30 million, these same plants could be fully equipped with emission control technology which would reduce emissions (and consumption) of mercury more than 75 percent (still leaving 81 tonnes entering the environment each year). The best solution seems to lie in phasing out mercury cell technology only as plant replacement becomes necessary.

For the paint industry only one alternative was considered -- complete removal of mercury from paint and the use of substitute materials. (Mercurials are used primarily in water-based paints for preservation purposes while in the can, and for protection against mildew formation in many exterior paints.) The most immediate impact of the alternative would be an increase in the cost of paint at the consumer level of at least 50 cents per gallon. A likely (but not totally demonstrated) side effect would be lower paint quality, which would necessitate more frequent painting. The net effect of substitution on the paint industry and its ancillary industries is actually a benefit, since additional capacity would be required because of the demands for more frequent painting (assuming the consumer tolerates the change). However, the cost to the consumer over the 10-year period would be an estimated $1.4 billion (accounted for by the increase of 50 cents per gallon). The benefit derived would be the elimination of more than 180 tonnes of mercury from the environment each year, primarily in the form of reduced emissions to air. (The loss of mercury from paint occurs primarily after the paint is applied, when the vapor transfers to the air.)

The use of mercury in high-energy-density batteries has become more prominent in recent years, and the forecast is for even greater usage in the future. While some substitutes are on the horizon, these are not seen as an important consideration for the period under study. Hence the only regulatory action considered was the use of "forced" recycling, which would have the net effect of reducing mercury losses to the environment--primarily to land. To "force" the necessary degree of participation for our case study, a regulatory screen was imposed upon the industry itself so that in one case 10 percent of all mercury purchases must come from recycled batteries and in the second case 25 percent of mercury purchases must come from recycling. (The details of the recycling were not explored, but a variety of schemes, based upon price incentives for individual returns, can be envisioned.) For 10-percent recycling the estimated reduction in mercury losses over the 10-year period was about 5 percent, while for the 25-percent recycling the reduction was about 20 percent for the same period. The associated costs were $3.8 million and $9.4 million respectively.

From the results of these two cases it appears that, in the long term, regulatory policy decisions threaten not so much "costs" as new equilibrium within the industry. The net effect, then, is not loss or gain, but redistribution. Thus regulations that force contraction of mercury-related industry will inevitably result in the expansion of other industries (which may merely represent conversions of the defunct mercury-related industry).

CONCLUSIONS

The results of this study lead to the following conclusions:

1. Mercury and its compounds are used in relatively low volume compared to other industrial chemicals, but these uses impact on a variety of areas and on all phases of the economy. Consequently, mercury discharges enter the environment at a number of points. Of particular concern is the characteristic of mercurials to move, after discharge, from one environmental medium to another and to enter man's food chain through various mechanisms.

2. Present monitoring capabilities for determining the concentration of mercury in the environment are inadequate, in both scope and reliability. Therefore the available data on ambient mercury levels do not provide a complete picture of either natural or elevated levels.

3. An input/output model of sources and uses of mercury and its compounds in the economy has proved very useful in determining the location and magnitude of discharge of material wastes to various environmental receptors.

4. About 80 percent of the almost 1,900 tons of mercury used each year in the United States is ultimately discharged to the environment; an additional 8 percent is recycled, and the remainder is permanently in place.

5. Differences are evident in use and discharge patterns between the various regions studied and the nation as a whole; these differences can generally be traced to industrial-type activities (which may include mining and smelting, combustion of fossil fuels, and manufacturing). When such perturbations are allowed for and discounted, mercury discharges can be shown to be a function of population density; for the nation overall, these discharges are estimated to be as follows: to air, 1.80 g per capita; to water, 0.39 g per capita; and to land; 4.25 g per capita.

6. For the United States as a whole, the percent distribution of mercury discharges from man-related sources to the various environmental receptors is: 31 percent to air; 6 percent to water; and 63 percent to land.

- Less than 5 percent of the man-related discharges to air are from regulated industries (i.e., chlor-alkali and mercury mining). Natural emissions (from degassing of the earth's crust) are estimated to be three times greater than the man-related discharges. The fate of mercury and its compounds in air is not clear (although they do not appear to present a direct hazard to man because of the low ambient concentrations), but the mercury eventually returns to the land and to the water.

- About 13 percent of the man-related discharges to water are from regulated industries (currently chlor-alkali and mercurials manufacturing). Natural sources (primarily runoff) contribute about two times as much mercury to water as do man-related discharges. Some mercury is removed from water in sewage treatment processes as sludge and is either returned to land or incinerated and returned to air. Most mercury discharged to water appears to be incorporated rapidly into sediments and may be released by biological and mechanical action over a period of time.

- Some 25 percent of the man-related discharges to land (as solid waste) are from regulated industries. Although mercury and its compounds appear in trace amounts in virtually all soils, these cannot be compared with man-related discharges. Solid wastes incorporated in regulated landfills (which currently receive about one-third of all solid wastes) do not discharge appreciable amounts of mercury to water; the discharge of mercury vapors to air from landfills is a possibility which needs further study. Also needed is additional study of mercury losses from improperly operated or unregulated landfills. Solid wastes which are incinerated do release mercury to air and are of major concern with respect to pollution.

7. The often expressed "threat to man" associated with the current rate of man-related mercury discharges to the environment has not, in fact, been conclusively demonstrated. Similarly, there is no conclusive evidence to indicate that a long-term buildup of mercury in the biosphere is occurring. Nonetheless, the potential consequences of a mercury buildup are of such magnitude that efforts should continue to decrease the quantities of mercury discharged each year.

8. Regulatory actions are most easily and best carried out at a "point source" such as a manufacturing or processing facility. However, the final consumption sector, which represents many points of discharge, accounts for 60 to 70 percent of all man-related discharges to air, water, and land. Because regulation of these "area sources" is extremely difficult, alternatives which impose regulation at more accessible points -- that is, the manufacturing or processing level -- will probably be more effective. Future regulatory actions should address the following areas:

- o Regulatory action should ensure that man-related discharges to air and water are minimized by requiring the adoption of the best available technology.

- o Federal regulations should serve as the basis for related state regulations, which can be adapted to fit with federal criteria.

9. Of the present "unregulated" industry-type discharges, copper smelters, fossil-fuel-burning power plants, and municipal incinerators are the most likely candidates for regulation, particularly with respect to emissions to air.

10. The total elimination of mercury as a way of reducing discharges is generally a most expensive choice; improved control over losses is much less expensive and may meet the desired objectives. Long-term regulatory policy may cause redistribution of industrial capacity but will have little effect on "costs" per se; however, costs are passed on to the consumer, and these are inevitably higher.

11. Mercury emissions are almost invariably associated with other types of toxic or noxious discharges. Multiple discharges from a single source should be treated as a common problem and attacked as such both at the regulatory end and in the technological approach. Mercury discharged to one

environmental receptor may be transferred to another receptor. Such intermedia transfer is best handled by one cognizant agency to ensure that controls on one medium do not adversely affect another.

12. Natural emissions, although appreciably greater than man-related emissions, are much more diffuse than are man-related discharges. Thus the fact that natural discharges are much greater in the aggregate should not be used as an argument that regulatory controls of man-related discharges are unnecessary.

13. This study indicates areas where regulations should be considered and may prove of value. However, such regulations should be developed only after further refinement of the data, with in-depth analyses of the affected industries and with the cooperation of these industries.

TECHNICAL FINDINGS

1. At present, there are not sufficient limitations to ensure minimization of the quantities of mercurial wastes which are discharged to the environment. The situation is particularly serious with respect to mercurials from consumer products (primarily batteries) discarded to land. To affect significant reductions it may be necessary for the manufacturing sector (and specifically battery manufacturers) to assume responsibility for recycling mercury-containing products. This would reduce manufacturing needs for virgin metal and would also reduce the amount of waste going to landfills. If new regulations are required to achieve such actions, they will need to be formulated in the light of several implications, including those listed below:

- Product substitution or elimination of mercury usage is desirable only when a potential hazard can be cited and only when it can be clearly demonstrated that emission control technology will not produce a sufficient reduction to mitigate the hazard.

- Regulation of mercury discharges from copper smelting, fossil-fuel-burning power plants, and municipal incineration would significantly reduce mercury discharges to air. (EPA has the power, under Section 112 of the Clean Air Act, to develop mercury emission standards for these sources because mercury has already been designated as a hazardous air pollutant.)

- New regulations, if developed in cooperation with the affected industries, would ensure the lowest redistribution impact on the specific industry, least cost to the consumer, and maximum benefits in terms of reducing mercury losses to the environment.

- Mercury discharges are generally associated with discharges of other hazardous substances; furthermore, the movement of mercury from one medium to another is a recognized phenomenon. An understanding of these interrelationships is most useful in the formulation of regulatory actions and technological developments.

2. In-depth data for all media (for selected study areas) would establish a baseline for ascertaining whether mercury is building up in the biosphere. (Little value is seen in adding mercury monitoring to routine analyses or on a nation-wide basis, although additional information on the natural mercury content of some widely used raw materials, such as natural gas, would be useful.)

3. The input/output model utilizing a computerized data base management system has been demonstrated to be a valuable approach for assessing losses of toxic materials to the environment. The model appears to be readily adaptable for more general use.

I

INTRODUCTION

BACKGROUND

Mercury and its compounds have been used by society since antiquity but did not come into widespread and varied usage until modern times. Mercury, which is unique because it is the only liquid metal in common use, finds numerous applications which utilize its conductive properties. Its compounds are some of the most effective mildewcides, pesticides, and preservatives available; they also have many industrial and agricultural applications. Mercury compounds serve as unique catalysts for certain reactions and are useful in some pharmaceutical applications. In addition, mercury's ability to amalgamate has led to its widespread use in dental applications.

However, although the use of mercurials* has developed as a necessary adjunct to society's growth, they have also earned a notorious reputation as toxic substances, and it is widely recognized that they can cause disabling sickness and death. While the mercurials have generally been treated with caution with respect to direct human exposure, it was not recognized until recent years that when they are discharged to the environment they can enter man's food chain and lead to illness and fatalities. Hence the unfortunate episodes in the late 1950s at Minamata and Niigata in Japan when industrial discharges of mercury to water entered the human food chain via fish, subsequently poisoning a significant portion of the population of these areas and introducing "Minamata disease" into our lexicon.

Alerted by the Minamata experience, governments and industry began intensive investigations of the pathway of mercurials into the environment and of the threat they might offer to man. It was quickly established that the alkylmercury compounds were by far the most toxic to man; they have a long residence time in the body (a biological half-life of 70 to 74 days) and cross both placental and blood-brain barriers. In the latter case, disabling damage can occur. It was further found that the labile substance mercury, through bacterial or biological action in the environment, can undergo changes from relatively innocuous forms to the very toxic methylmercury, which can be concentrated in the food chain.

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* For simplicity, the term "mercury" or "mercurials" will be used henceforth to mean both mercury and its compounds, unless otherwise specifically noted.

As a result of these findings, industrial discharges and many pesticides and preservatives which heretofore had not been regulated were identified as being harmful to the environment and to man, and immediate steps were taken both by the government and by industry to limit or eliminate unsafe and unnecessary applications. Several problem areas were identified (for example discharges to water from chlor-alkali plants* using mercury cell technology) and corrective actions were taken to limit such discharges. Other, more stringent actions were taken with the suspension of all uses (including manufacture) of any of the alkylmercury compounds. In yet other instances the U.S. Environmental Protection Agency (EPA), which had become very instrumental both in identifying the extent of the problem and in ensuring that industrial discharges were brought into compliance with standards, had taken action to force the cancellation of the use of mercurials as biocides and preservatives.

As a result of the recognition of the situation and the actions taken to alter it, the total use of mercury in the United States has dropped significantly (from 73,560 flasks in 1965 to 54,289 flasks in 1973).** Perhaps more significantly, a number of uses of mercury were completely eliminated, in cases where substitute materials or alternate processes could readily be adopted. For example, mercury was formerly used (albeit in small quantities) for the recovery of gold by an amalgam process; mercury is no longer used in this application.

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* Throughout the report, when we refer to chlor-alkali plants, unless otherwise noted we mean plants that use mercury cells.

** A flask of mercury contains 34.4 kilograms (76 pounds); there are approximately 29 flasks in a metric ton (2,205 pounds).

Likewise, mercurials were long used as preservatives in the lumber, pulp, and paper industries; today these uses have also been eliminated.

Why, then, since the use of mercury is decreasing, its discharge to the environment is under better control, and its properties of concentrating in the food chain are now recognized, is an additional study of mercury necessary? There are several reasons. First, some researchers are very concerned about the possibility that any mercury unnecessarily introduced into the environment becomes available to the so-called "mercury cycle" (which is discussed in detail later) and leads to increasing concentrations in the environment. In short, because of its unique properties mercury may continue to recycle indefinitely within the biosphere. According to adherents of this theory, strict limits should be placed on the introduction of mercury into the environment in order to minimize the present and potential impacts created by the gradual and continued increase of mercury in the cycle. (For more detailed descriptions, see Refs. 1-4.)*

The concern regarding possible increases of mercury in the biosphere has led to more monitoring for mercury and to its discovery, albeit in low levels, almost universally.** Appendix A gives more details concerning our present understanding of mercury sources and cycling and of its effects on the air, water, and land environments.

The recognition that mercury is widespread, if not ubiquitous, has given rise to a second school of thought which theorizes that mercury is naturally present in the environment as a result of degassing from the earth's crust and as runoff from natural erosion processes. These natural processes add to the available mercury in the biosphere at a constant rate, but as yet there is no evidence to support the belief that there has been a sharp increase in global mercury concentrations in the last 50 to 100 years (Refs. 5-8). Therefore, a second school of thought has arisen which holds that the processes that maintain an equilibrium with respect to natural emissions easily handle the small additional discharges that are man-related. Those who adhere to this theory feel that the natural processes tend to maintain some sort of equilibrium between mercury discharged into the environment and that removed by natural processes, so that even rather large quantities of man-related discharges do not adversely affect the mercury balance worldwide or over a long period. (However, these people are not advocating any relaxation of controls on discharges which can directly or indirectly enter man's food chain.) On this premise, the need to reduce or eliminate mercurials in certain industrial applications has been strongly questioned by some industry representatives. In particular, the goal of eliminating mercurials as biocides and preservatives is contested. Industry representatives also point out that unregulated emissions from such sources as power plants burning fossil fuels are permitted--and the quantities involved are appreciable--whereas the known beneficial uses are to be prohibited.

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* Numbered references are listed at the end of this report.

** Until recently, one of the difficulties in evaluating the presence of mercury has stemmed from the use of analytical techniques which often were limited to 0.5 part per million (ppm) or greater and whose reproducibility of results was poor. More sophisticated analytical techniques--primarily thin layer chromatography (TLC)--have now been developed which can reliably detect mercury in concentrations as low as one part per trillion (ppt).

Man-made emissions, however, are usually localized and thus may result in localized high concentrations. In the past this was true of emissions to water from, say, a chlor-alkali plant. Emissions to water have recently come under strict regulation, but localized emissions to air (for instance from an incinerator or power plant) from unregulated sources may indeed pose hazards.

Two questions seem to be still unresolved. First, what are the sources that contribute mercury to the biosphere, and what are the quantities involved? If in answering this question it can be shown that certain of these sources can be limited or even eliminated, then the second question must be addressed. This question is: what will be the impacts of such restrictions? (We will not deal at this time with the suggestion that introduction of mercury into the environment is beneficial rather than detrimental, but will adhere to the general conclusion that unnecessary introduction of mercury into the environment is indeed undesirable.) The EPA, seeking answers to these two basic questions, has funded the study whose results are reported here.

SCOPE OF WORK

The EPA set forth the following scope of work for the study: "The contractor shall prepare a detailed materials balance on mercury and its compounds. He shall assess quantitatively the distribution on an input/output basis nationally and for selected geographic regions. He shall include estimates of the environmental fate of the quantities necessary to close the balance. In addition, the contractor shall consider current and projected process technologies for mercury products, indicating how alternative technologies influence the materials balance. He shall carry out analyses of economic and market trends that affect the materials balance, and assess the feasibility of substitute processes and materials that will significantly reduce the amounts of mercury entering the environment."

This scope of work is designed to answer the two questions posed in the previous section. By identifying all sources that discharge mercury into the biosphere and the relative quantities discharged, and by deriving a materials balance indicating the final disposition of this mercury (fixed in place or discharged to land, air, or water), the relative importance of both sources and discharges can be evaluated. A part of this concern is the ultimate fate of mercury, recognizing that movement between the earth, water, and air is characteristic of the cycling of mercury.

The study considered both national and regional materials balances; regional inventories were made to ascertain differences which may exist between regions and to accent special problems which may be peculiar to certain regions. The study also considered those points where mercury enters the environment for which better controls (which may include substitution or elimination) may exist. Since the introduction of controls is certain to have economic impacts (with possible social implications) and may also entail certain risks to society, both the costs and benefits of instituting such controls were considered and their impact on the marketplace was evaluated. The basic objective of the study, then, was to determine the need for additional controls on mercury discharges and the cost to the individual and to the overall economy for implementing such controls, as related to the benefits accrued.

METHOD OF APPROACH

A sequential study approach was used, beginning with the inventory (including an input/output model with a materials balance), which considers all sources in identifying major perturbations and differentiates major from minor contributors. Next a technology assessment was made which considers, for major contributors only, technological actions which might be taken within the next 10 years to appreciably reduce the emissions of mercury to the environment. Finally, the economic impact of regulatory controls on major users of mercury was evaluated.

An input/output model for the mercury economy can be readily derived, since annual production and consumption figures are available (these include data with some degree of reliability concerning recycling of mercury and releases from the national stockpile). At the national level, a number of material balances had been made previously. A pioneer effort was completed by Davis in 1968 (Ref. 9), and there have been several updates (Refs. 10-13). Other independent estimates have been made by other investigators. Thus the input/output model as a concept is well established and the study inventory was based upon these earlier results. However, this study, which is keyed to the year 1973 with estimates for 1983, also afforded an opportunity to include later and better estimates.

The introduction of a regional inventory is a new concept. It permits making comparisons of various regions to determine if significant variations occur, thus making it possible to identify special problem areas. At the same time, making the regional inventory is very complicated, because the values utilized for the national estimates must be adapted to the specific region under study, where national values no longer apply. (The inventory and its concomitant materials balance utilize emission factors dealing with the proportions of mercury lost to air, water, land, or recycling. In some cases these factors must also be tailored to the specific region studied, even though the variations may be slight.)

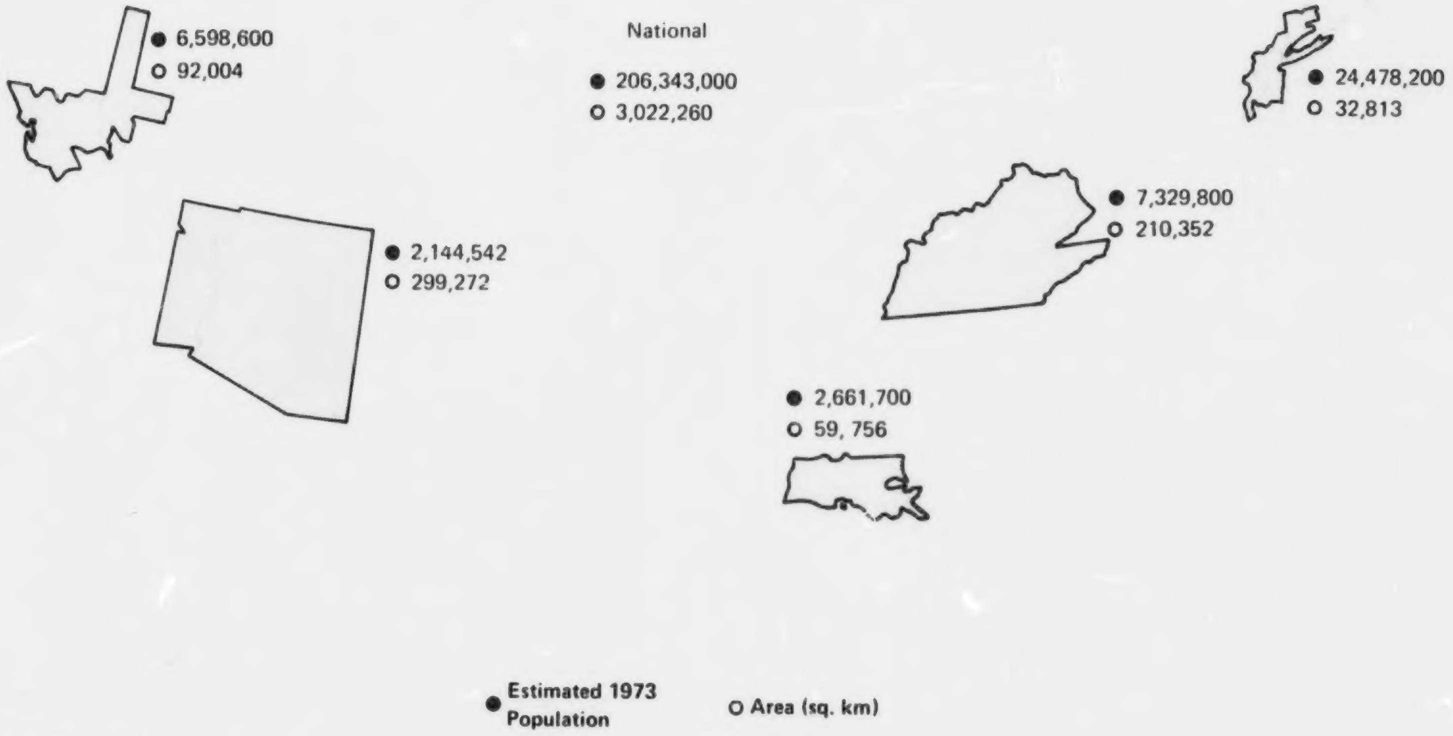
Five regions were selected for study on the bases of (1) known discharges as derived from the EPA permits program, (2) known high discharges to air or water, and (3) to a lesser degree, differing socioeconomic characteristics of the regions. It was hoped that the discharges identified for a given region might correlate with ambient mercury values in that region; however, ambient readings are generally inadequate to permit such correlation. This problem is discussed in greater detail subsequently.

Study regions were selected on the basis of a map prepared by the Office of Toxic Substances of the EPA that shows elevated mercury concentrations in the United States. This extensively researched map showed:

- High and low discharges of mercury to water according to permit applications in the RAPP file
- High ambient air readings from unknown sources
- High ambient water readings from unknown sources
- Known mercury deposits
- Known gold and silver deposits

From this map it was possible to see that certain regions have a probability of unusually high discharges of mercury to the environment from natural and/or man-related sources. These "high discharge" regions, which are shown on Figure 1, were also selected with a view to geographical distribution, population characteristics, and manufacturing activity. A brief discussion of the regions is given in Appendix B.

Technology assessment is concerned only with those sources of mercury which can potentially be controlled (and thus excludes natural contributions) and which are important contributors. This assessment, then, deals with location of discharges and quantities involved and with control technology which is or may become available to reduce discharges. In addition, alternative materials or processes which would substantially reduce or entirely eliminate requirements for mercury are assessed. The technology assessment reported here provides a state-of-the-art study for each source of mercury considered important and an estimate of the degree to which further controls on that particular source might effectively reduce the quantity of mercury reaching the environment. This assessment indicates where additional technological improvement (including substitution of products or processes) might be of considerable value. The assessment also identifies for more detailed study


● 6,598,600
○ 92,004
National
● 206,343,000
○ 3,022,260
● 24,478,200
○ 32,813
● 7,329,800
○ 210,352
● 2,144,542
○ 299,272
● 2,661,700
○ 59, 756
● Estimated 1973 Population
○ Area (sq. km)

SOURCE: URS Research Company

Figure 1 STUDY REGIONS

the major man-related sources of mercury discharged into the environment that are amenable to regulation.

As an adjunct to the technology assessment, an investigation was made of the ultimate fate of mercury in the environment--how it may move endlessly between land, air, and water. Of particular concern here is the adequacy of present waste disposal techniques (particularly with regard to landfills, sewage treatment plants, and incinerators) in minimizing the potential for discharged mercury to recirculate in the environment.

The study of the socioeconomic impacts of imposing regulatory controls to reduce mercury discharges considered both the assumed benefits and the shortcomings of several use alternatives. These alternatives include using other chemicals to replace mercury in existing processes and products, alternative processes to produce the desired products, and alternative final use products which might obviate the need for mercury precursors. Any of these alternatives may involve risks such as the introduction of other toxic or undesirable byproducts into the environment or a direct impact on the user in terms of reduced yield, less satisfactory product performance, etc. Since benefits are not derived directly but are based on the total reduction of mercury discharged to the environment, risks must be treated as part of total cost. Total cost thus includes, in addition to the cost represented by risk, a variety of economic indicators and techniques which must apply to the specific industry under investigation. The cost versus benefit analysis, then, reflects the cost of reducing the amount of mercury entering the environment by a certain fraction (or absolute number). The willingness of the public to endure such costs to meet specific goals in reducing mercury emissions must then be assessed.

REPORT ORGANIZATION

Subsequent sections of the report provide the details of the methodology and results from which the conclusions and recommendations presented in the executive summary are derived.

Section II is a historical overview and outlook summary for mercury usage. This section provides insights into current trends in the consumption of mercury and lays the groundwork for the remainder of the report by giving a first iteration of future trends. The "mercury economy," which ranges from mining to manufacturing to consumption to final disposal and then to the ultimate fate of mercury in the environment, is described, as are legislative implications. The section provides much background information but is not essential to the understanding of the remainder of the report.

Section III describes the input/output model and the methodology employed in determining losses of mercury to the environment. The results for the five study regions are presented and compared with those for the national inventory. Implications on possible risk to the population and the importance of control over emissions which may enter man's food chain are discussed. Finally, a description is given of the inventory results as the basis for selection of technologies for more detailed study.

In Section IV technologies which entail unusually heavy usage of mercury and/or the possibility of substantial losses of mercury to the environment are considered. Technologies from each sector of the mercury economy -- that is, mining, manufacturing, final consumption, and final disposal -- are considered. For each technology considered, current (1973) and foreseeable (1983) technology is discussed in detail. Where applicable, the sites of emissions are specified and alternatives which might be considered to reduce such emissions are indicated. Finally, estimates of total losses to the environment for 1973 and 1983 are presented.

Section V deals with the probable economic impact of regulatory actions designed to lower mercury emissions to the environment. Chlor-alkali plants using mercury cell technology, which account for large losses in the manufacturing sector, are analyzed. In the final consumption sector, two high volume users of mercury are considered: water-based latex paints and high energy density mercury-containing dry cell batteries.

Backup materials and additional details of results are presented in the appendixes.

II

HISTORICAL OVERVIEW AND OUTLOOK SUMMARY

Efforts to reduce man's exposure to mercury require an understanding of ways in which it is lost to the environment and of its ultimate fate. This section summarizes the recent history of, and projected technical and commercial outlook for, the principal sources, consumption, and final disposal of mercury. The ultimate fate of mercury in the environment is also summarized here. This information provides a basis for the analysis of the mercury input/output balance and the investigation of means of reducing losses of mercury to the environment. Finally, existing legislation on the regulation of mercury and its compounds and trends in regulation are discussed briefly at the end of this section.

SOURCES OF MERCURY

The principal sources of mercury entering U.S. commerce include:

1. Domestic primary production and stockpile
2. Net imports for consumption (imports less exports)
3. Recycled (secondary) mercury

Between 1960 and 1973, domestic primary production dropped from 33,223 to 2,131 flasks; stockpiles ranged widely over the period, reaching a high of 31,764 flasks in 1965, but in 1972 fell to 512 flasks and in 1973 totaled 2,583 flasks. Secondary sources reached highs of 10,000 or more flasks in some years during the 1960-1973 period, but overall averaged 5,000 to 8,000 flasks annually. Net imports in 1960 were 18,814 flasks; by 1973, net imports contributed 45,734 flasks.

PRESENT AND PROJECTED MERCURY CONSUMPTION

Between 1962 and 1969, growth in mercury consumption averaged 2.1 percent per year, but from 1969 through 1973 consumption actually declined by 30 percent overall, at an annual average rate of 8.5 percent. This decline can be attributed chiefly to (1) the apprehension of mercury users concerning the probable tightening of legal restrictions, (2) the reduction of emissions by caustic chlorine (chlor-alkali) producers, and (3) the 1972-1973 business recession. The low point was reached in 1971, when consumption was 52,725 flasks. In 1973 consumption increased slightly, to 54,283 flasks, and preliminary data for 1974 indicate a 10.7-percent increase over the 1973 level.

World market prices have been very volatile during the period 1960-1973, but price trends have not been the controlling factor in the use of mercury. Instead, price has depended largely on the production costs of marginal producers who have had to demand higher prices for their output. As the demand for mercury has declined, the price has fallen and mines have closed down. During the 1960s, when prices topped $700 per flask, 149 mines were in production in the United States. However, the Bureau of Mines reports that only five mines were producing in the first quarter of 1974, when the average price was about $286 per flask. In part, the decrease in producing mines was caused by the speculation which took place in mercury (as well as in other metals), which led to excessive inventories and ultimately drove prices down.

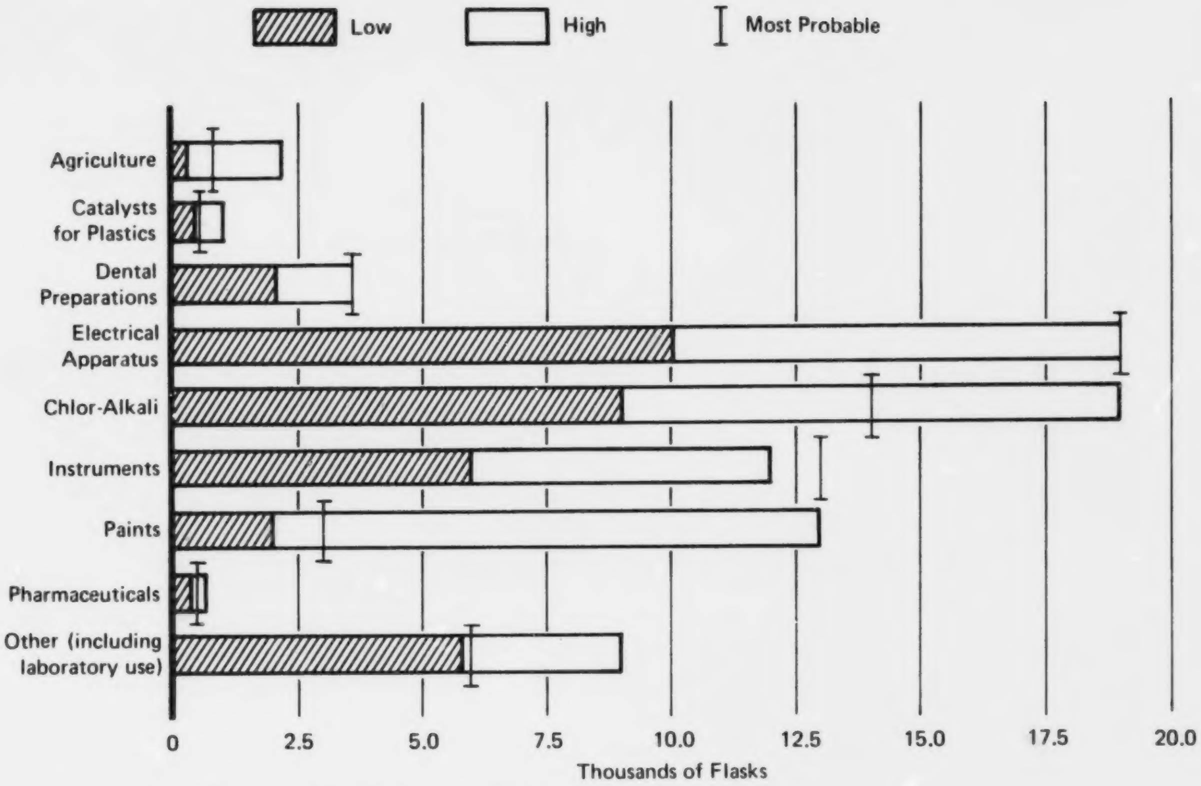
Forecasting the demand for mercury ten years in the future is a complex task. Population growth is one obvious factor that must be considered, but the development of new manufacturing processes and substitutes to avoid the adverse effects of mercury in some applications has introduced new uncertainties in forecasting. For one thing, legal constraints may militate against the economics of using mercury. In many instances, the substitutes used in order to comply with governmental regulations are less economic (and sometimes less effective) than the mercury or mercury compound they replace.

Recent consumption data for the principal end uses of mercury and mercury compounds in the United States are listed in Table 1, according to use categories established by the U.S. Bureau of Mines. Figure 2 gives a range of estimated values for 1985 made by the Bureau of Mines. Forecasts derived by URS Research Company in the current study are also shown; for the aggregate demand, they are probably accurate to between ±10 and ±15 percent of the figures shown. For specific uses, the accuracy is more likely to be in the ±10 percent area.

TABLE 1. - Mercury Consumption in the United States, 1965-1973, by End Use
(number of flasks)

End Use	1965	1966	1967	1968	1969	1970	1971	1972	1973
Agriculture	3,116	2,374	3,732	3,430	2,689	1,811	1,478	1,836	1,830
Amalgams	268	248	219	267	195	219	-	-	-
Catalysts	924	1,932	2,489	1,914	2,958	2,238	996	800	673
Dental preparations	3,196	2,133	2,386	3,079	2,880	2,286	1,871	2,983	2,679
Electrical apparatus	18,887	17,638	16,223	19,630	18,490	15,952	16,646	15,553	18,000
Caustic chlorine	8,753	11,541	14,306	17,453	20,720	15,011	12,252	11,519	13,070
Laboratories	2,332	2,217	1,940	1,989	1,936	1,806	1,357	594	658
Industrial instruments	10,330	7,294	7,459	7,978	6,655	4,832	3,906	6,541	7,155
Paint (antifouling)	255	140	152	392	244	198	414	32	32
Paint (mildew proofing)	8,211	8,789	7,026	10,174	9,486	10,149	8,192	8,190	7,571
Pulp and paper	619	612	446	417	558	226	2	-	-
Pharmaceuticals	418	232	283	424	712	690	668	578	606
Other	16,251	16,359	12,856	8,275	9,134	6,085	4,943	4,280	2,009
Total	73,560	71,509	69,517	75,422	77,372	61,503	52,725	52,907	54,283

Source: Ref. 14.



SOURCES: High and low forecasts: Ref. 14; "most probable" forecast: URS Research Company.

Figure 2 PROJECTED MERCURY CONSUMPTION IN THE UNITED STATES, BY END USE (34.4-Kg Flasks)

MAJOR END USES

The following summary discussion of the outlook for the principal use categories for mercury elaborates on the forecasts presented in Figure 2.

Agriculture

The principal agricultural use of mercury is for seed dressing; lesser amounts are used for disease control of certain crops. No effective and harmless substitutes for these uses have been found to date, but continuing research should result in the development of equally effective but less potentially harmful substances over the next decade. The EPA has already banned the use of alkylmercury compounds, and prohibitions on the use of all other mercury biocides are anticipated. By 1985, agricultural consumption may have declined to some 800 flasks a year, for some limited applications that will undoubtedly be under strict governmental supervision.

Catalysts

Catalysts containing mercury have been used in the production of vinyl chloride monomers, urethane foams, and anthraquinone derivatives. The production of urethane foams is expected to continue to increase in the years ahead, and no wholly satisfactory alternative catalyst has been found, although for some purposes the organotins have been substituted. Vinyl chloride monomer production has shifted to increasing use of ethylene rather than acetylene. It was the acetylene process which used mercury-based catalysts. The URS forecast anticipates this decrease in use for vinyl chloride monomers, with some offsetting increases for the urethane foams.

Dental Preparations

Population growth and rising affluence, coupled with the increasing number of health care plans which cover dental costs, account for much of the projected increase in mercury use for dental preparations. Newer technologies in dental restorations could reverse this trend; at present, however, it does not seem that replacements for mercury amalgams will be found during the forecast period. Furthermore, the use of mercury in dental preparations has been shown to be essentially harmless to humans, and its effectiveness is well known. Thus, the total probable demand forecast by URS for 1985 is the same as the high figure shown in Figure 2.

Electrical Apparatus

The projected high demand for mercury in electrical applications reflects population growth and continued demand for mercury batteries and lamps. Note, however, that it is not significantly greater than the 1973 consumption figure shown in Table 1. Declines in military battery requirements have been more than offset by increased nonmilitary usage. The low forecast in Figure 2 assumes significant replacement of the battery uses by other systems and further replacement of mercury rectifiers by solid-state devices. The URS demand forecast reflects stabilization of recent demand trends and the probable lack of large-scale, radical departures from current manufacturing materials and processes over the next decade.

Caustic-Chlorine (Chlor-Alkali)

The Chlorine Institute has forecast a 6-percent annual increase in chlorine production through 1980. In Figure 2, the high production of 19,000 flasks of mercury consumption by 1985 is based on: (1) an extrapolation of projected chlorine production through 1985; (2) production of about 24 percent of total chlorine through mercury cells; and (3) a continued makeup rate of 0.37 pound (lb) of mercury per ton of chlorine produced. The low figure of 9,000 flasks assumes that: (1) the 1985 output of chlorine by the mercury process will remain at the current level of 2.4 million tons; and (2) mercury consumption in this process will decline to 0.10 lb per ton of chlorine produced.

It is quite likely that the makeup rate will drop to around 0.30 lb of mercury per ton of chlorine produced by 1985, due to implementation of EPA standards. In addition, several mercury cell production units have closed in recent years and the mercury cell plant share of chlorine production has declined 15 percent between 1968 and 1972. On the other hand, the 13-percent jump from 1972 to 1973 suggests that the 9,000-flask figure is probably too low. The 1985 projection of 14,000 flasks derived by URS is believed to be more realistic. (Note, however, that none of the new plants that will be producing caustic-chlorine in the near future uses the mercury cell.)

Paints

Increasing use of the less toxic organic fungicides and preservatives is expected to restrain the use of mercury compounds in the manufacture of paints over the next decade. The high demand figure (13,000 flasks) in Figure 2 is based on increased, rather than decreased, consumption of these compounds, in line with the forecast 3.7-percent annual growth for paint. The low figure assumes a complete ban on mercury compounds in paints by EPA, while the URS forecast assumes special uses under controlled conditions.

Over the last decade, the development of emulsion paints has led to a swift rise in the use of organomercurials for mildew prevention to extend the shelf life and durability of the product. This use will likely continue at least for the near term--up to five years--since development of fully satisfactory replacements will take nearly that long. It should also be noted, however, that this application generally has been declining in recent years. In marine paints, the mercurials are antifoulants; this use of mercurials declined, however, to a low of 32 flasks in 1972 and again in 1973, in sharp contrast to consumption during the preceding five years.

Pharmaceuticals

The high forecast of 700 flasks of mercury for pharmaceutical end uses in 1985 reflects the impact of expected population increases on present (1972-1973) demand levels; the low figure assumes elimination of all mercurial preparations, except for special uses where no substitutes are known. It appears to URS that a 1985 figure of 500 flasks for this end use is a reasonable estimate.

Other Uses (including Laboratories)

The high and low demand levels shown in Figure 2 for 1985 were based on Gross National Product (GNP) and population growth factors, respectively. The URS forecast, which is closer to the low figure, is based on the assumption that there will continue to be a steady demand for mercurials for general laboratory chemicals and pigments, and that new uses are also likely to arise.

Consumption by Federal Agencies

In 1971, in a very comprehensive study (Ref. 82), a survey was made of federal agency usage of mercury that indicated that the Department of Defense and the Atomic Energy Commission were the largest users. This study was sufficiently thorough that we were not able to improve upon it during the present work.

REGIONAL DISTRIBUTION

The two largest outlet categories for manufactured goods in the United States are merchant wholesalers and manufacturers' sales branches and offices. The U.S. Census of Business lists totals for product classes passing through these outlets, and divides these totals into nine Census regions. Table 2 shows results of an attempt to determine regional sales of mercury-containing products and to relate these data to regional population figures. Some data are available from manufacturers' associations in the East. However, it is not always possible to obtain data that differentiate between mercury-containing and nonmercury-containing products. In such cases, the "mercury portion" of total production can be estimated from the gross usage figures in Table 2 and from knowledge of the average mercury content of one unit of product.

In theory, the sum of the regional sales should equal the U.S. total for each type of outlet. The total of the outlets plus minor distribution systems should yield an approximation of the total domestic market for any given product class. In fact, however, relatively few sums "checked" closely or exactly. Fortunately, one or the other (merchant wholesalers or manufacturers'

TABLE 2. - Sales of Manufactured Products Containing Mercury (percentage sold, by Census region, compared to region's share of U.S. population)

U.S. Census Region	Paints	Pharm.	Agric. Chem.	Lamps	Switches and Rectifiers	Dental Amalgam	Laboratory and Hospital Supplies	U.S. Population (12/73)
New England	3.7%	4.4%	0.3%	5.8%	6.2%	6.4%	5.7%	5.8%
Middle Atlantic	23.2	23.7	12.3	17.8	31.3	27.6	23.7	17.8
East North Central	23.7	20.1	24.0	19.4	15.2	17.4	18.6	19.4
West North Central	6.5	8.2	16.1	8.0	7.1	7.8	7.8	8.0
South Atlantic	11.1	14.1	7.4	15.5	10.7	10.4	12.5	15.5
East South Central	3.3	3.6	10.3	6.3	2.5	4.4	4.5	6.3
West South Central	7.9	9.2	11.0	9.7	6.8	6.5	8.0	9.7
Mountain	2.1	2.2	2.8	4.4	2.5	3.9	2.9	4.4
Pacific	18.6	14.3	15.3	13.1	18.5	15.6	16.1	13.1
Totals[a]	100.1%	99.8%	99.5%	100.0%	100.8%	100.0%	99.8%	100.0%

a. Totals may not add, due to rounding.

Source: Derived from current Census data, USDA data, and information supplied by the following manufacturers' associations: National Paint and Coatings Association; American Hospital Association; American Dental Association; and Pharmaceutical Manufacturers Association.

sales branches) checked within reason for all product classes. Only in pharmaceuticals did both column totals agree, yielding a consistent picture of the total market.

Note the significant differences between the consumption of agricultural chemicals and the proportion of national population in the Atlantic and Central regions, and the disproportionately large consumption of mercury-containing products generally in the Middle Atlantic Region. In spite of the statistical difficulties in estimating the extent of mercury consumption in manufactured products, the preliminary data in Table 2 are considered reasonable approximations of the markets for such products.

FINAL DISPOSAL

Prior to the recognition in 1970 that mercury and its compounds had some unusual characteristics which allowed it to enter man's food chain and adversely affect him, mercurials had received little more attention than had the other heavy metals. Certain industries had been recognized as sources of mercury in the environment, and certain pollution controls were in effect. However, because mercury was usually lost to the environment in smaller quantities than other pollutants, special treatments aimed solely at mercury had not been developed. At first, the major concern was with mercury discharges to water, because these led most directly into the food chain. The development of controls on water emissions was also expedited because it was relatively easy to monitor for mercury in water in the parts per million (ppm) range.*

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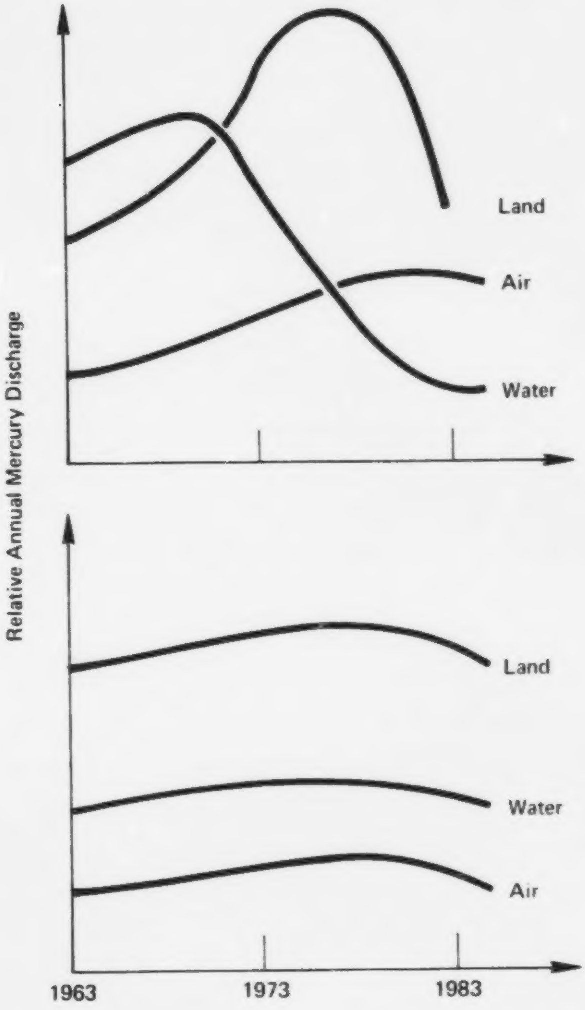
* Even at the parts per million level difficulties were experienced in obtaining consistent and reliable monitoring data (see Ref. 67 for the ROUND ROBIN evaluation made by the EPA). However, the data obtained were considered sufficiently reliable to establish standards. Further, water lends itself to continuous or intermittent sampling whose results, combined with known flow rates, can be used to calculate total discharge. Such a calculation cannot easily be made for either air or land emissions.

Industrial emissions to air where exposure of workers was a recognized possibility had been under surveillance, if not regulation, for many years, so that excessive discharges were at least discouraged (if not prohibited). However, with recognition of the threat and imposition of stricter control on air emissions, the quantities emitted to air by regulated industries began to decrease sharply in the early 1970s. Even so, a number of known mercury emitters, such as coal-burning steam electric plants and copper smelters, still remain unregulated and continue to emit quantities of mercury to the air. These industries are concerned with the control of other pollutants and have as yet not been very concerned with concomitant emissions of mercury, which on a mass basis represents only a tiny fraction of the major pollutant, sulfur dioxide. Thus, at the present time, the unregulated emitters probably represent the largest "industrial" source of mercury emissions to air, and will likely continue to do so in the future. However, the increasing concern with controlling the emission of major pollutants may well result in decreased emissions of mercury.

Industrial discharges of mercury-containing solid wastes were never considered as a major problem, since the assumed insolubility and stability of mercury compounds were well recognized. However, it is now recognized that mercury can migrate through the soil to the groundwater or even be emitted directly to the air. This has led to increasing concern with isolating these industrial landfills by more sophisticated methods, such as the use of impermeable liners and other procedures to ensure segregation from groundwaters. It is anticipated that, as pressure continues to reduce the loss of mercury to the environment in any form, industrial discharges to land will continue to decrease--primarily through better process control, which may include internal recycling.

Figure 3a is the URS estimate of past and future trends with respect to the discharges of mercurials from industrial and unregulated sources to air, land, and water. These curves sketch out only trends and relative quantities involved, but they provide some interesting insights. For example, we have reason to believe that in 1963 most industrial discharges were directed into the watercourses. This trend was probably accelerated in the late 1960s by



(a) INDUSTRIAL AND UNREGULATED SOURCES

(b) MUNICIPAL SOURCES

SOURCE: URS Research Company.

Figure 3 PAST AND PROBABLE FUTURE TRENDS IN FINAL DISPOSAL OF MERCURIALS

the sharp increase in the construction of new chlor-alkali plants using mercury cells. After the imposition of strict controls in early 1970, discharges to water dropped sharply, but at the same time the discharges to land (which then became the recipient of much of the material previously discharged to water) rose sharply. Even today (in 1975) discharges to water are but a fraction of what they were five years ago. This trend will continue but will taper off by 1983, because a near-irreducible minimum will have been reached. The forecast is that industrial and unregulated discharges to land will level off and thereafter decrease sharply as better utilization of mercury in industrial processes is required. Even so, we feel that land will continue to be the largest single recipient of industrial discharges of mercury.

Industrial discharges to air are believed to have increased somewhat in the 1963-1973 period, despite the imposition of regulatory standards on chlor-alkali facilities and on mercury smelters. This increase is primarily attributable to the increased use of fossil fuels with higher mercury content (for which no regulatory action as yet has been proposed). The increased use of fossil fuels (primarily coal) for electric power generation may increase emissions to air over the next ten years, but regulatory standards will probably be imposed that will lead to an ultimate decrease in emissions.

Municipal discharges of mercury to the environment had never been considered to be a significant problem. After the 1970 alert, however, research on mercury discharges in municipal sewage was instigated and demonstrated that appreciable quantities can be attributed to that source. It was recognized that the incoming water source often had a detectable mercury content, which might represent 10 to 20 percent of the mercury content of the untreated sewage.

The emission of mercury in sewage was still not considered a serious concern. In general, it was thought that discharges through municipal sewage were probably small in comparison to industrial discharges to water and that the discharges from the municipal sources were in any event scattered uniformly throughout populated areas (in contrast to industrial discharges, which were not). Further, the removal of the low levels of mercury found in sewage presented a formidable--and indeed impossible--task.

Problems with mercury in sewage sludge, which accumulates about half of the mercury in the influent (raw) sewage, have stirred the most recent concern. If this sludge is used in landfill operations, no serious problems are likely to be created. However, if it is incinerated (as is done in a number of municipalities) or used as a soil amendment, the mercury can then be transferred to the air or to plants. The forecast is that the incineration of sludges will decrease in the future, because of the now known release of mercury as well as other toxic materials into the atmosphere, and that the total quantities released via this route will be lowered. The use of soil amendments is also likely to come under stricter control.

By far the largest loss to the environment from municipal sources is that to land, normally in landfill operations. Most mercury used in consumer products such as batteries or lamps is finally relegated as solid waste to landfills. The quantities involved in this case probably exceed those from industrial sources (although, of course, the disposal sites for the two types of wastes are segregated). There has been little concern with the accumulation of mercury-containing products in landfills, since there is little or no evidence to indicate that mercury escapes from properly designed landfills of types that are coming into common use. Hence the forecast is that municipal landfills will continue to receive and treat mercury-containing products in the future much as they have done in the past. However, the total quantity of mercury disposal to landfills will decrease, for two reasons. One reason is the probable decrease in the quantity of mercury being incorporated in consumer products because of the forced recognition by industry of mercury's potential for environmental harm. Second, as recycling becomes more popular consumer salvage of mercury-containing products, particularly batteries, is more likely. Nevertheless, the total amount of mercury in landfills is now large and will continue to grow with the years.

Mercury enters the air as a result of incineration of solid wastes or of sludges. Incineration and other thermal conversion processes such as pyrolysis are not general practices today (although incineration is common along the Eastern seaboard), but they are likely to become more popular as energy sources in the future. Even today, incinerator stack gases have been identified as containing excessive quantities of mercury. Because they are currently unregulated sources of mercury, incinerators have no pollutant control devices specifically to remove mercury, although they do have pollution control devices for such primary air pollutants as particulates, and these do act to reduce mercury emissions. Hence it is forecast that in the near term discharges to air from incineration of solid wastes and sludges will continue to rise, but that with the recognition of the threat this entails, the mercury-containing products will be segregated so that in the future such discharges from municipal sources will decrease.

Our evaluation of past and future trends with regard to municipal sources is summarized in Figure 3b. Again, the quantities indicated are purely for illustrative purposes and, aside from those for land, are considerably less than the quantities related to industrial and unregulated sources.

ULTIMATE FATE OF MERCURY IN THE ENVIRONMENT

The fate of mercury in the environment is determined by its origin, the medium into which it is lost, the conditions imposed on that medium, and transformations occurring within that medium (Ref. 15). For instance, airborne mercury lost from a chlor-alkali plant disperses rapidly in the environment, due to diffusion and dispersive action of wind (Ref. 16). Some mercury concentrates in nearby soil and water sediments, but because most of it is in a volatile form, the largest percentage of the emitted mercury becomes part of the regional or global atmospheric burden, with little effect on ambient regional concentrations. Emissions to the atmosphere from other large sources such as smelters, incinerators, and coal-fired power plants would follow similar patterns. In these cases, there would be relatively large increases in atmospheric, soil, and water concentrations in the local area (Ref. 17). The cumulative effects of many such sources measurably increase regional concentrations and may indetectably increase global concentrations, as shown by recent global modeling efforts (Refs. 1, 15). With regard to natural atmospheric sources, high ambient air concentrations have been found near mineralized and geothermal areas (Ref. 18). The fate of this mercury is similar to that from point sources, but there is less effect on ambient concentrations because of the generally dispersed nature of natural sources. Atmospheric mercury is returned to the terrestrial environment through precipitation and dry deposition; the ocean and its deep sediments constitute the ultimate sink for some of this mercury (Ref. 15).

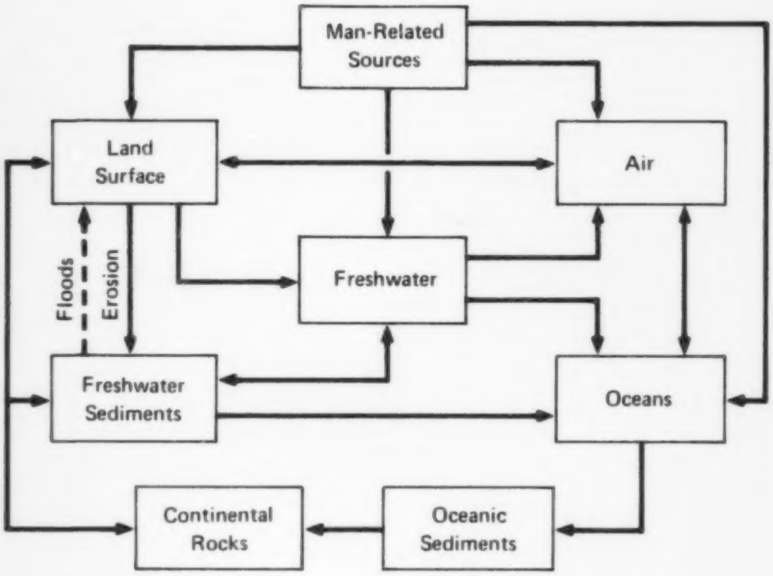
Mercury emitted directly into rivers is usually adsorbed onto suspended particles in the rivers and consequently is found in the sediments (Refs. 19, 20). However, such deposition is only a temporary fate, as biological and chemical activity leads to volatilization that sometimes reduces the sediment concentrations to background (equilibrium) levels (Ref. 21). Also, deposited sediment is continually resuspended and is carried downriver by periodic floods, eventually reaching the ocean. Mercury entering estuaries and bays generally remains in such waters longer than in more rapidly moving streams. Lakes experience even longer residence times for mercury and tend to accumulate higher concentrations in both the sediment and the water column. The absence of turbulence in lakes also slows the exchange of mercury with the atmosphere (Ref. 22).

Man and nature contribute significant quantities of mercury to the land environment. Directly, mercury-containing industrial and municipal solid wastes are deposited in landfills. Indirectly, emissions from atmospheric sources add to the burden of mercury in the land; natural degassing also contributes indirectly.

Generally, mercury losses from solid waste deposited in landfills can be well controlled through proper disposal site selection, design, construction, operation, and maintenance. Improper disposal practices can contribute mercury to water (primarily groundwater) and air environments (Refs. 17, 18).

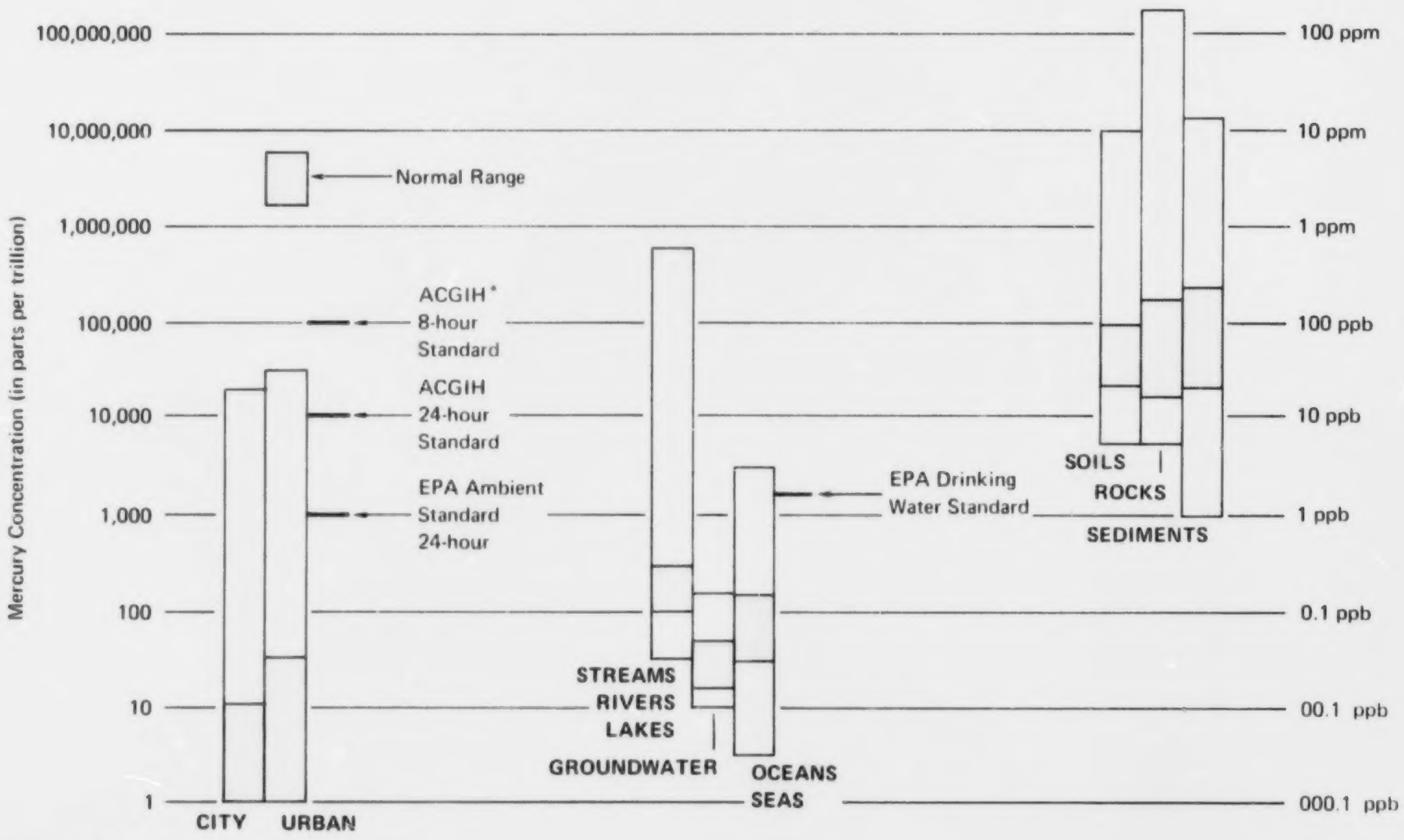
Figure 4 shows the various major environmental "reservoirs" and the transfer paths of mercury among these reservoirs. The critical role of biota in the mercury cycle is not indicated, but should be emphasized with respect to its effect on transfer rates and mechanisms and with respect to the potential health problems related to mercury contamination. In terms of rates and mechanisms, microbial communities catalyze the formation of the mobile alkylmercurials and volatile methylmercury. The production of methylmercury leads to the public health concern, because members of the food chain (especially fish) have the ability to concentrate methylmercury.

Little information has been collected with regard to interreservoir transfer (except on a global basis), although much information has been collected on the concentrations of mercury in the materials which make up these environments. Figure 5 is a summary of measurements for both normal and


Man-Related Sources
Land Surface
Air
Floods
Erosion
Freshwater
Freshwater Sediments
Oceans
Continental Rocks
Oceanic Sediments

SOURCE: Ref. 19.

Figure 4 MERCURY CYCLING THROUGH ENVIRONMENTAL "RESERVOIRS"



* American Congress of Governmental Industrial Hygienists.
SOURCE: URS Research Company.

Figure 5 VARIATIONS IN MERCURY CONTENT OF THE ENVIRONMENT IN RELATION TO EXISTING STANDARDS

contaminated environments. Most of these data were collected from special studies.

National monitoring data on a regular basis are available only for mercury in water, as the National Soils Monitoring Program does not monitor mercury on a regular basis and the SAROAD (Storage and Retrieval of Aerometric Data) network contains only a few measurements. The water quality monitoring system, STORET (Storage and Retrieval of Water Quality Control Information), contains a limited number of mercury measurements for streams and lakes, with the best data available for the East Coast.

LEGISLATION AND REGULATIONS APPLICABLE TO MERCURY

This analysis of legislation and regulations involving mercury and mercury compounds deals primarily with federal agencies. Prior to 1970 there were no government regulations specifically applicable to mercury or mercury compounds as a health hazard to man. Four federal agencies had the authority in existing legislation for such regulation, but had not used it. The U.S. Food and Drug Administration (FDA) had the authority, under the Federal Food, Drug, and Cosmetics Act of 1938, to control mercury in food products. The U.S. Public Health Service (PHS) had authority to control mercury in public drinking water supplies; however, current standards (adopted in 1962) do not consider mercury. The U.S. Department of Agriculture (USDA) had authority to control mercury in pesticides, under the Federal Insecticide, Fungicide, and Rodenticide Act of 1947. The Federal Water Quality Administration had authority under the Clean Water Act of 1966 to establish standards for interstate waters; however, only the standards of Illinois have a limit on mercury--0.5 part per billion (ppb).

Mercury Crisis: The Early Response

In 1969, 1970, and 1971 a series of unrelated incidents (see listing below) aroused public concern and prompted action by the U.S. Congress and federal regulatory authorities. Congress responded to the "mercury crisis" by incorporating more specific regulatory authority in a variety of new legislation. A series of Congressional hearings in 1970 provided the first major public forum for an airing of the impacts of mercury on man. Subsequent hearings on specific legislation also dealt in part with mercury pollution. The FDA's initial monitoring activities were directed toward mercury contamination in fish, and in 1970 the agency established a guideline of 0.5 ppm mercury in fish. This guideline was not a standard, and the only significant action by FDA was to recommend in 1971 that swordfish not be eaten.

Year	Event
1969	Alamagordo poisoning case
1970	Tuna confiscated by FDA in fall
	Mercury found in Lake St. Clair fish (note sent to U.S. Secretary of State by Canada, April 2)
1971	FDA recommended that swordfish not be eaten
	6,530 persons poisoned in Iraq by mercury-coated seeds
	First reported case of mercury poisoning from fish consumption in United States

Source: Ref. 15

The EPA was formed in 1970, and was given the responsibilities of the PHS, USDA, and the Federal Water Quality Administration for control of mercury. The EPA responded to the "mercury crisis" through several regulatory avenues (as outlined below).

Existing legislation is directed toward controlling discharges of mercury to the environment as waste matter or in pesticides. Pending toxic substances control legislation authorizes the EPA to evaluate chemical substances and to regulate or prohibit the use of those determined to be toxic. Such substances would include those containing mercury.

Regulatory Guidelines and Actions

Early EPA efforts to regulate the discharge of mercury are outlined below, followed by a discussion of subsequent legislation that redefined or strengthened EPA's regulatory authority in each of the environmental sectors considered.

The Air Environment

The Clean Air Act of 1970 authorized EPA to establish national standards for hazardous air pollutants. The law did not specifically denote mercury as such a pollutant. However, on the basis of evidence that mercury is emitted by coal-burning power plants, municipal incinerators, and industrial plants, in March 1971 the EPA designated mercury as a hazardous air pollutant (36 FR 5931). Standards for mercury were proposed in December 1971 (36 FR 23239) and were promulgated as regulations in April 1973 for mercury ore processing facilities and chlor-alkali plants (see Table 3).

The Land Environment

Beginning in 1970, EPA took a series of actions to cancel pesticides that contained mercury, under authority obtained from the Department of Agriculture. The Federal Environmental Pesticide Control Act of 1972 strengthened EPA's authority to regulate, control, and cancel harmful pesticides, including those containing mercury.

The Water Environment

Under the Drinking Water Act of 1974, EPA was given the authority to propose and promulgate standards for mercury in drinking water. The proposed standard is 0.002 ppm, which is much more strict than the previous standard of 0.005 ppm. The most widely known action taken by EPA in this early period involved application of an old law to a new situation. In 1970, the agency conducted a nationwide survey to determine mercury levels in surface waters. Based on these results and on the Rivers and Harbors Act of 1899, EPA proposed

TABLE 3. - EPA Mercury Regulations

Federal Register	Date	Applicable to	Standard
38 FR 8820[a]	4/06/73	Mercury ore processing facilities and chlor-alkali plants	2,300 gm/24-hour period
38 FR 35388 (proposed) (39 FR 10603 amendment)	12/27/73	Paper and allied products; oil and gas extraction; industrial organic or inorganic chemical; alkalis and chlorine; ferrous metal production; nonferrous metal smelting and rerefining; lumber and wood products; bituminous coal and lignite mining; storage or primary battery manufacturing; or metal mining facility discharging into navigable water	(1) Into streams, lakes, or estuaries with flow less than 10 cfs or lakes less than 500 acres --no discharges; (2) other streams and lakes--20 µg/ℓ per discharge or 1/10th this concentration when low flow is less than 10 times the waste flow; (3) other estuaries and all coastal waters-- 100 µg/ℓ per discharge or 1/10th this concentration where low flow is less than 10 times the waste flow; (4) stream--not to exceed 0.000162 times flow in cfs (or) 1.62 lbs/day; (5) lake--not to exceed 0.000135 times flow in cfs (or) 1.35 lbs/day; (6) estuary--not to exceed 0.00027 times flow in cfs (or) 2.70 lbs/day; (7) coastal water--not to exceed 0.000324 times flow in cfs (or) 3.24 lbs/day
38 FR 28610	10/15/73	Ocean dumping	No mercury except as trace contaminants
39 FR 38064	10/25/74	Wastewater treatment plant sludge incinerators	3,200 gm/24-hour period

a. 38 FR 8820 = Vol. 38, Federal Register, page 8820.

Note: This table does not include regulations dealing with pesticides. There have been and continue to be many such regulations, all involving either cancellation or suspension of pesticide use; however, limitations of time and space have precluded listing them here.

standards for mercury discharge into surface waters, at rates dependent upon the type of receiving water body. Since then, several states have enacted their own limitations on mercury discharges to water from a given emitter or class of emitters.

The Federal Water Pollution Control Act amendments of 1972 gave EPA the basis for enforcing the regulation of mercury discharges into the water environment. In September 1973, EPA designated mercury as a toxic pollutant (38 FR 24342), and in December 1973 the agency proposed toxic pollutant effluent standards, which were amended in March 1974 (Table 3). In October 1973, EPA issued regulations prohibiting dumping any material containing mercury into the ocean. The agency has also designated mercury compounds (-acetate, -ammonium chloride, -bromide, -chloride, -cyanide, -iodide, -nitrate, -nitrate, -oxide, -sulfate, and -thiocyanate) as hazardous substances, and any person or entity spilling such substances is liable for cleanup and/or fine (38 FR 30466, August 1974). In October 1974, standards for mercury emissions from wastewater treatment facilities were proposed.

Interstate Transportation

One form of governmental regulation not mentioned previously concerns the interstate transportation of hazardous substances. Many mercury compounds are designated as Group B poisons by the U.S. Department of Transportation, and their shipment is regulated in accordance with applicable regulations. Also, because metallic mercury readily amalgamates with aluminum, the shipment of metallic mercury by air is restricted by the Civil Aeronautics Board.

Trends in Legislation and Regulatory Action

Toxic substances control legislation has been introduced in Congress during the last three legislative sessions, but bills introduced in 1971 and 1973 failed to survive House and Senate conferences. In February 1975, a revised bill (S.776) was introduced in the Senate. The intent of this legislation is to provide more careful evaluation of new chemicals prior to their commercial introduction and to provide adequate federal authority to deal with toxic substances now in the environment. The EPA will have the primary responsibility for implementing the legislation if it is passed. The legislation is being challenged, primarily by the chemical manufacturing industry, as being too costly for the benefits to be gained, and as restrictive of industry efforts to develop and market new products. The EPA has responded with much lower cost estimates and with arguments in support of the legislation as necessary for both human and environmental protection.

The continuing efforts on the part of Congress and the EPA to enact legislation for the control of toxic substances indicate that if the legislation now before Congress is not enacted, other attempts will be made in the future. In the long run the prognosis for enactment of such legislation is good; however, compromises made to secure its passage could reduce the effectiveness of the legislation from that now being contemplated. If this did occur, the legislation would doubtless be tightened over the years, as seems to be the trend with most environmental legislation.

The major issue is the cost to be incurred by the chemical manufacturing industry to comply with the federal regulations. The present economic environment in the United States, coupled with recent administrative positions taken on environmental legislation that cause industry to incur additional costs, indicate a very high probability that such legislation, if passed in the immediate future, would be vetoed. If the economic situation improves, the justification for vetoing such legislation would decline, of course.

If no new legislation is enacted in the short term, the EPA can be expected to continue to use control mechanisms that now exist with respect to toxic substances. The EPA has continued to regulate pesticides and has recently promulgated controls on other toxic substances through the use of provisions of the water and air acts. While these are not source controls, EPA actions taken after introduction of substances into the environment (such as banning such substances in air and water discharges) will force consumers to consider more carefully the use of substances with toxics in them.

In summary, the EPA will continue to use existing authority to control toxic substances. New legislation can be expected that will more explicitly define the EPA's authority in the control, including source control, of toxic substances, but the probability that such legislation will be enacted in the next two years is much lower than it is for the succeeding five years.

III

INPUT/OUTPUT ANALYSIS

INTRODUCTION

The usefulness of a national inventory of mercury sources and emissions in deriving rough estimates of the quantity of mercury entering the environment from man-related sources has been apparent for some time. Davis (Ref. 9), in a comprehensive effort for the year 1968, used a simple model to estimate mercury losses to air, land, and water from industrial, consumer, fuel-burning, and sewage treatment activities; he introduced the concept of an emission factor (the term "Davis emission factor" refers to values he established). Anderson (Ref. 10) updated some of the industrial emission factors and provided considerable information on emission factors from combustion of fossil fuels. Roy (Ref. 11) provided additional inputs on the mercury discharges associated with sewage and sludges. An EPA internal document presented other inputs using the same model, which were finalized in 1974 in a working paper, "Mercury Pollution in the United States, by Source Category" (Ref. 12), which served as the point of departure for the inventory reported here.

These inventories have several points in common:

- o Estimates are made on a national basis for emissions for a stated year.
- o Bureau of Mines data on the number of flasks of mercury consumed in that year are the basic input data.
- o Emission factors are applied to determine what fraction of the total available mercury is lost.

In addition, some of the inventories include estimates for unregulated sources (primarily fossil fuel burning, sewage, and sludges) and natural sources.

The URS inventory was expanded to incorporate an input/output (I/O) analysis with a materials balance to ensure that all sources were included and yet that no double accounting occurred. The basic goals in preparing this inventory were:

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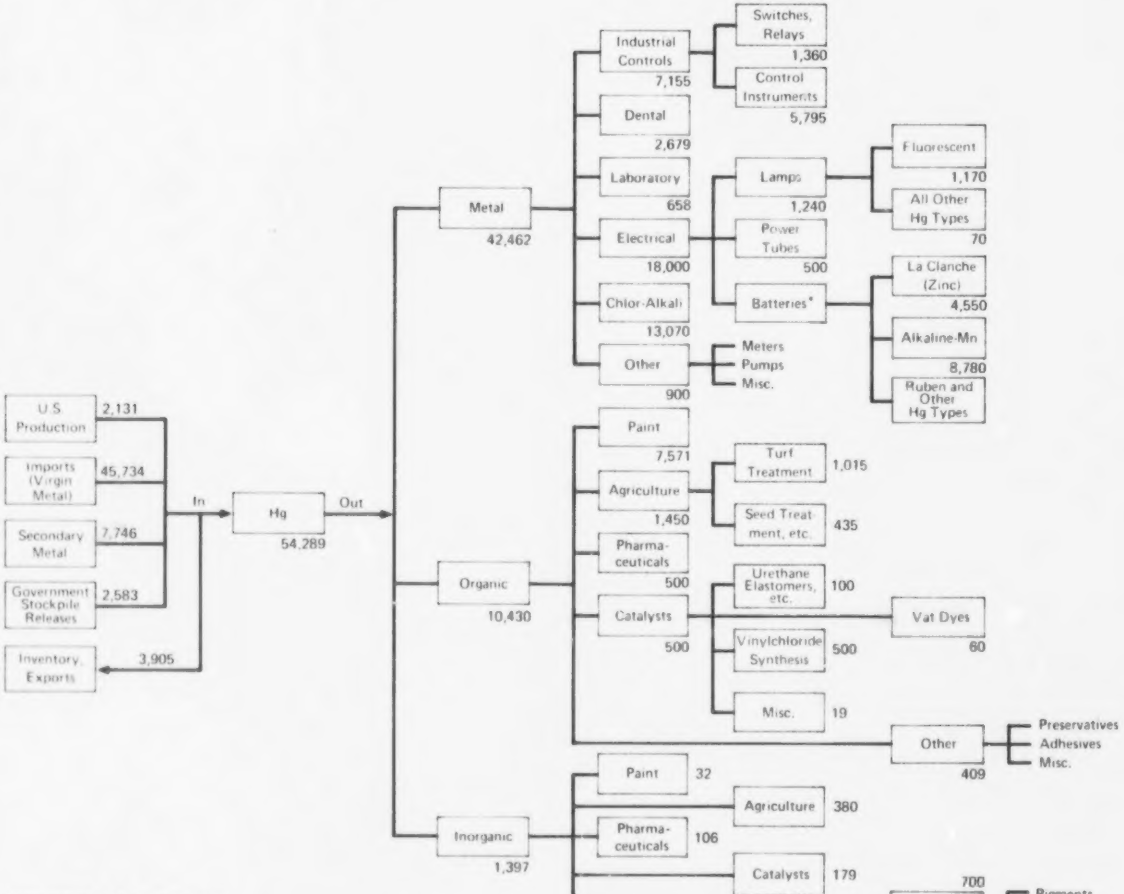
- To verify and update, where required, the latest available inventory (Ref. 12), including all sources of mercury to the environment on a national basis.
- To prepare a materials balance for selected regions which have been identified as having unusually high ambient mercury readings and/or an unusual number of known mercury emission sources.
- To determine from the national and regional inventories where the major losses of mercury to the environment have occurred and what the nature of these losses was. Under this item the ultimate fate of mercury in the environment was to be considered to ascertain if final disposal (primarily to land) indeed represented the ultimate fate, or if transfer to other media was a concern.

METHODOLOGY

The development of an input/output (I/O) model which would provide the information outlined above required the development of suitable methodology not only for the model but also for establishing a data base to support this model. Because the two are so closely interrelated, the development of the methodology for one proceeded simultaneously with that for the other.

First let us consider the state of the art of I/O models available for mercury at this time. The several models described above were based almost entirely on data provided by the Bureau of Mines. Our initial efforts also relied primarily upon the Bureau of Mines data. We first developed a flow chart (shown in Figure 6) which shows the sources of mercury used in the United States in 1973, together with the industrial and commercial uses to which this mercury was directed. In 1973 the double impact of lower mercury prices on the world market and restrictions on allowable emissions from mercury mining and smelting operations in the United States had effectively reduced domestic mercury production to very minor quantities (2,131 flasks, or 3.9 percent of total domestic usage). The supply/demand gap created by this decreased


U.S. Production
2,131
Imports (Virgin Metal)
45,734
Secondary Metal
7,746
Government Stockpile Releases
2,583
Inventory, Exports
3,905
In
Hg
54,289
Out
Metal
42,462
Industrial Controls
7,155
Switches, Relays
1,360
Control Instruments
5,795
Dental
2,679
Laboratory
658
Electrical
18,000
Lamps
1,240
Fluorescent
1,170
All Other Hg Types
70
Power Tubes
500
Batteries*
La Clanche (Zinc)
4,550
Alkaline-Mn
8,780
Ruben and Other Hg Types
Chlor-Alkali
13,070
Other
900
Meters
Pumps
Misc.
Organic
10,430
Paint
7,571
Agriculture
1,450
Turf Treatment
1,015
Seed Treatment, etc.
435
Pharmaceuticals
500
Catalysts
500
Urethane Elastomers, etc.
100
Vat Dyes
60
Vinylchloride Synthesis
500
Misc.
19
Other
409
Preservatives
Adhesives
Misc.
Inorganic
1,397
Paint
32
Agriculture
380
Pharmaceuticals
106
Catalysts
179
Other
700
Pigments
Stabilizers
Misc.

* Used primarily in the inorganic form.

SOURCE URS Research Co., based on Bureau of Mines data

Figure 6 SOURCES OF MERCURY AND INDUSTRIAL AND COMMERCIAL USAGE IN THE UNITED STATES, 1973 (All values in number of 76-pound flasks)

domestic production was primarily filled by imports from other countries. Secondary metal production (from recycling within the nation) was little changed from previous years, accounting for 14.3 percent of consumption. Releases from government stockpiles accounted for another 4.8 percent of consumption. (Some 3,905 flasks were diverted from supply into inventory buildup, export, or unaccounted losses.)

Figure 6 also indicates the several categories of usage to which mercury is assigned and the relative quantities involved. It does not indicate the losses to the environment from these categories (these losses will be discussed later in the report). It should be recognized that this flow chart, while useful, has limitations and inconsistencies which have been resolved to the degree possible. For example, the Bureau of Mines data reports only usage of the electrical applications. From a variety of references, none of which agreed completely with any other, we were able to break this usage down further, into lamps, power tubes, and batteries. Still further division of lamp and battery usage was possible. However, in many applications such detailed breakdowns are at best tenuous. In particular, the "other" category, which represents a rather heavy usage of mercury, is so broad that further tracing is impossible.

Figure 6 indicates that less than 20 percent of the mercury used is in the organic form. The vast majority is used in metallic form, and the remainder is in the inorganic form.* We needed a comprehensive model that would allow us to track mercury from its introduction (input) into the economy, through its use at various stages within the economy (including losses during transfer or by accident), and thence to final disposal of discarded products. In addition, we had to recognize that a number of unregulated sources exist that contribute to mercury losses to the environment. Finally, we knew that natural sources also contribute mercury to the environment, although the extent of their contribution was not clear. And in our study, all of these losses to the environment had to be traceable not only on a national basis, but also on a regional basis.

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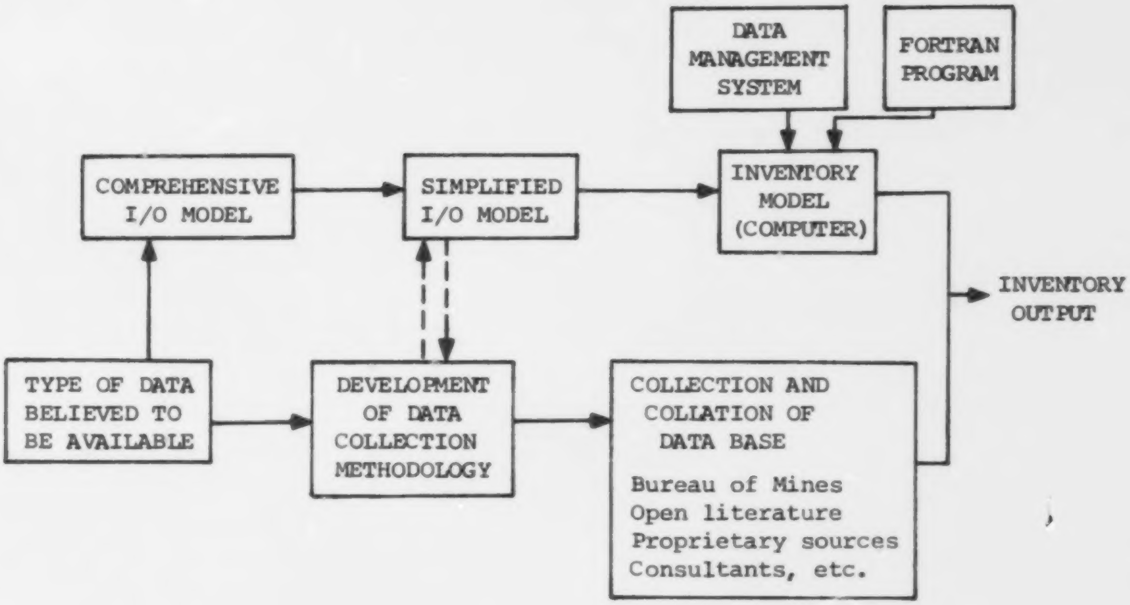
* In the flow chart the battery industry is shown as using only virgin mercury metal, which is not entirely correct. Battery makers purchase only the virgin metal and convert it, in their own facilities, to mercury oxide and other inorganic salts for incorporation into their products (with a minor quantity for sale to other users). Thus when taking into account the inorganic mercury usage of the battery industry, the form of mercury discharged to the environment is more likely: metallic 50 percent, organic 19 percent; inorganic 31 percent.

The basic framework of the methodology which we adopted to develop both a suitable input/output (I/O) model and the necessary inputs to support it is sketched below:

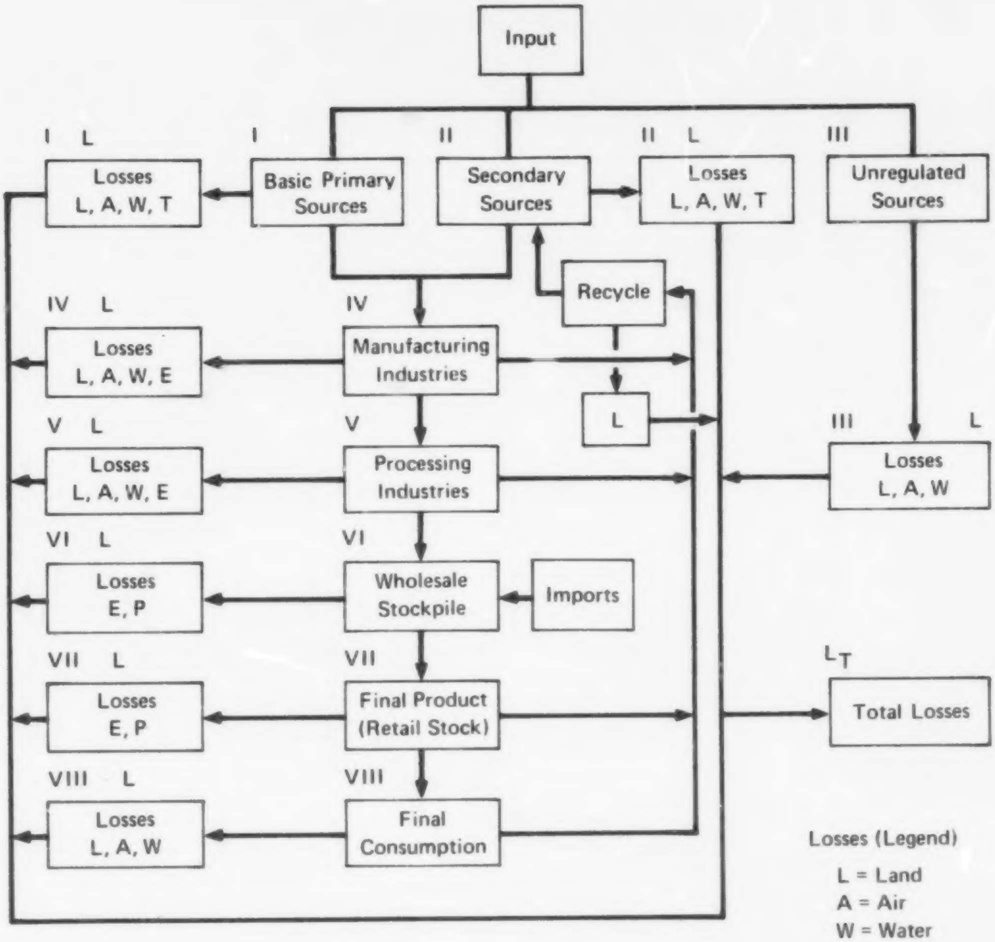

DATA MANAGEMENT SYSTEM
FORTRAN PROGRAM
COMPREHENSIVE I/O MODEL
SIMPLIFIED I/O MODEL
INVENTORY MODEL (COMPUTER)
INVENTORY OUTPUT
TYPE OF DATA BELIEVED TO BE AVAILABLE
DEVELOPMENT OF DATA COLLECTION METHODOLOGY
COLLECTION AND COLLATION OF DATA BASE
Bureau of Mines
Open literature
Proprietary sources
Consultants, etc.

As a first step, a systems analyst, working in conjunction with the data collection team, outlined a comprehensive I/O model, which was "pretested" to determine its applicability. It was discovered that the model was too cumbersome for adaptation to computer usage, so a simplified I/O model was derived. At the same time, the development of the simplified model solidified the data requirements, which led to the development of the data collection methodology. Again interaction was maintained between the systems analyst developing the simplified I/O model and the members of the data collection team (as shown by the dashed lines in the sketch), to ensure compatibility of these two mainstreams. The simplified model was then adapted for use on a PDP-10 computer. Meanwhile, the data base for the first study region (California) had been assembled. These data were subsequently analyzed using the inventory model and the desired output was obtained. (As with any such model, debugging was necessary, and as with any such large data base, newer information was frequently encountered and had to be incorporated.) Of course, some modifications were made in both the data collection methodology and the inventory model during the course of the study. In the following sections, however, we report only the final versions.

Development of an Input/Output Model

A conceptual model (see Figure 7) was designed to accommodate all possible inputs and outputs and to track man-related losses of mercury from both regulated and nonregulated sources in the environment. The model is comprehensive and, with adequate data, it is possible to trace all inputs, regardless of source, through manufacturing, processing, trade, final consumption, and thence to final disposition. The model recognizes the possibility of mercury loss not only to air, water, and land, but also to export (although this is not a true loss, of course). In addition, the model considers the possibility of loss by accident (the probability function) and in transit (the transfer function).

This model, although useful for conceptual purposes, required a degree of knowledge concerning regional inputs and outputs which proved unavailable (tracing the movement of a very small volume product such as the mercurials through interstate transfer was among the most difficult problems encountered). The program was therefore modified and simplified so that the materials flow from one sector to the other was eliminated but losses from each sector were maintained, and these were then accumulated. The final sectors in this simplified model are shown in Table 4. (A complete list of all sources under each section is presented in the discussion of the data base.) In addition to the six sectors shown in Table 4 which are an integral part of the I/O model, two


Input
I L
Losses
L, A, W, T
I
Basic Primary Sources
II
Secondary Sources
II L
Losses
L, A, W, T
III
Unregulated Sources
Recycle
IV L
Losses
L, A, W, E
IV
Manufacturing Industries
L
III L
Losses
L, A, W
V L
Losses
L, A, W, E
V
Processing Industries
VI L
Losses
E, P
VI
Wholesale Stockpile
Imports
VII L
Losses
E, P
VII
Final Product (Retail Stock)
L_T
Total Losses
VIII L
Losses
L, A, W
VIII
Final Consumption

Losses (Legend)

L = Land
A = Air
W = Water
E = Export
P = Probability
T = Transfer

SOURCE: URS Research Company.

Figure 7 BASIC MERCURY INVENTORY FLOW CHART

TABLE 4. - Input/Output Model Sectors

Sector	Name	Example
I	Mercury input	Mercury mining and refining
II	Mining	Copper mining and smelting
III	Misc. unregulated sources	Livestock manure; fossil-fuel-burning power plants
V	Manufacturing and processing	Battery manufacturing; catalysts
VIIIA	Commercially oriented final consumption	Fluorescent tubes; control instruments
VIIIB	Personally oriented final consumption	Dental applications; batteries
--	Final disposal	Sewage treatment; incineration
--	Natural sources	Degassing; runoff

Source: URS Research Company

other sectors--final disposal and natural sources--are listed. These sectors are listed separately because they represent neither a true input nor a true output. Final disposal, which includes sewage treatment, incineration, and landfill operations, encompasses the treatment and disposal of those mercury losses previously reported in the numbered sectors; its inclusion in the overall balance as a separate category could lead to double accounting.*

The massive quantity of data expected to be derived for each study region dictated that use of the I/O model, even in its simplified form, would require the speed and accuracy inherent in computer operations. To this end URS utilized a data management system leased from TYMSHARE, INC. (an international computer timesharing system) to store and analyze the mercury data collected during the study. This system, used on the PDP-10 computer, is referred to as System 1022; it is compatible with the conceptual model described above. System 1022 is a sophisticated, general-purpose, data management, software system. It allows the user to create, update, and maintain large data bases, features a very fast retrieval capability, and allows interface with FORTRAN source programs. The 1022 system categorizes the input data into a form that can be retrieved and updated quickly and efficiently. Special command files can be generated to make the system usable by individuals who have little or no computer experience.

Since a basic requirement in the study was to determine the areal distribution discharges of mercury to the environment, an initial problem was to determine the smallest geographical unit to be considered. The best definition would, of course, result from using the smallest unit, say a Census tract; however, the resulting number of units for even a small region would be astronomical. Furthermore, few data are available even at the level of the city, the Standard Metropolitan Statistical Area (SMSA), or the county (or parish). Some data, particularly commercial and industrial data, are available only at the state or regional level. A compromise was reached in using the county as the base for which all data would be accumulated. (As will be discussed later, for specific facilities location by latitude and longitude is possible for special analyses.)

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* Both sewage and solid wastes do include some mercury in the form of a natural background; however, these are small in comparison to man-related losses and do not influence the findings of the study.

Just as the county served as the basic unit of area, the Standard Industrial Classification (SIC) served as the basic unit of source. Each known or suspected emitter was assigned to an SIC which generally related to those found in the Standard Industrial Classification Manual of 1972. However, we modified these numbers (which are generally four digits) to meet our own requirements where necessary. For example, the manual classes SIC 2851 as paints, varnishes, lacquers, enamels, and allied products and includes establishments primarily engaged in their manufacture. However, we used 2851M to indicate the manufacture of the phenylmercuric acetate used by the paint industry, 2851F to indicate the formulation of the paint itself, and 2851P to indicate final consumption of the paint.

Each SIC was then assigned to one of the sectors shown in Table 4, in keeping with the I/O model. A list of the inputs into the I/O data management system is given in Table 5. Those concerned with location or classification have either been discussed or are self-evident. However, those concerned with "hard" data on the quantities of mercury and emissions to the environment require further clarification. The "inventory" input accounts for mercury which is either stocked by a user or is part of a nonconsuming process (such as chlor-alkali plant). (In practice, data for this listing proved to be difficult to derive and were generally not included.) The total quantity of mercury which is "exposed" for loss to the environment, as estimated by the data collection team, was input as "PROD." The inventory program then used a simple function to determine losses to the environment, namely:

PROD × emission factor = loss.*

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* Initially, additional entries had been allowed for total loss for a given facility. However, the few cases where such usage was necessary did not warrant the retention of this option; the functions listed above were easily substituted in its place.

TABLE 5. - Inputs into the Input/Output Inventory Program (for a given program)

Input	Description	Purpose
Sector	Generic description of sources	To classify similar sources together
SIC	Standard Industrial Classification	To standardize, in common usage, each individual source
Name	Used for manufacturer's facility	To differentiate between several SIC's at the same location
County	County (in some cases groups of counties) or parish	To identify by geographical location
State	--	--
Latitude/ Longitude	In Mercator coordinates	To permit location, within ±4 km, where desired
Inventory	Estimated quantity of mercury kept but not consumed	To distinguish inventory from losses
Total Quantities Produced or Processed (PROD)	An estimate of the total mercury consumed, in product or process, annually	The base value to which emission factors are applied
Form of product or process	Designates major form of emission -- Hg, inorganic or organic	To allow a determination of the form in which mercurials are lost to the environment
Emission Factors (EF) Air Water Land Recycle	An EF represents the fraction lost to each output. (The sum of all EF's cannot exceed 1.0, but may be less, due to increased inventory or permanent retention of the mercury in PROD.)	Used in program to determine losses to the environment. For example: PROD x EF_A = loss to air; PROD x EF_W = loss to water

Source: URS Research Company

Emission factors are a widely used concept to represent the fraction of the total available mercury (that is, PROD) which is lost to a given environment. (Note that "recycle" has been treated as an emission since this simplified the computer program.) The sum of the emission factors is 1.0. However, in those instances where mercury can be shown to be permanently retained (for example, 75 percent of the mercury used in dental treatment is permanently retained in the teeth), the true amount lost to the environment is accounted for by an "availability factor," in this case 25 percent.

Six computer programs were developed, in the FORTRAN IV programming language, which are used in conjunction with the 1022 system to accept the indicated inputs and provide the desired outputs. These programs are described briefly in Table 6. The bulk of the information which will be reported on here was derived from ALLSIC, which lists, for a given region, all losses (by SIC) to the environment; CTYALL, which provides county-by-county listing of total mercury losses to the environment; and URSLL, which provides, within any given coordinate points, all mercury losses to the environment. Changes in the emission factors can be made by simply accessing System 1022 as outlined in Appendix C.

Acquisition of the Data

It was recognized that it would be a monumental task to acquire data on the utilization of mercury and its compounds on any but a gross (that is, national) basis. The first obstacle is the lack of substantive statistics on the use of mercury and its compounds; this lack is attributable to the very low volume of usage. (The Bureau of Mines is undoubtedly the best source of information, although the Tariff Commission provides some limited data on organic mercurials.) A second problem arises from the "scare" philosophy which has grown out of the highly publicized incidents in the early 1970s, and which has resulted in the reluctance of many users to discuss their present or projected utilization of mercurials. Many manufacturers are believed to underestimate their usage of mercury. In order to overcome these two major obstacles as far as possible, URS assembled a data collection team which included chemical engineers, a chemical economist, a regional economist,

TABLE 6. - Outputs from Various Programs in the Input/Output Model (for a given region)

Program Name	Output	Purpose
ALLSIC	Provides an enumeration of mercury losses, by SIC, to air, land, water, and recycling.	Permits identification of major sources of loss, by SIC, to each environmental recipient (air, water, or land).
CTYALL	Provides an enumeration of mercury losses, by county (or state), to air, water, land, and recycling.	Permits identification of major contributors, by county (or state), to each environmental recipient
URSLL	Provides an enumeration by latitude and longitude, of all mercury losses within an area designated by four coordinate points.	Permits study of losses to each environmental recipient in geographical locations of special interest (such as a river basin).
URSIC	Provides a correlation, for a given SIC, between the number of emitters and their size. Five size ranges are considered from <5 lb/yr to >400 lbs/yr.	Permits an assessment of the importance of size of emitter as compared to the total number of such emitters, by SIC.
URSCTY	Provides a correlation, for a given county, between the number and size of emitters, by sector. Five size ranges are considered from <5 lb/yr to >400 lb/yr.	Permits assessment of relative importance of contributors to environmental losses from different types of counties
MULFAC	Provides the capability to change total mercury usage (PROD) for a given SIC.	Allows rapid revisions of input data

Source: URS Research Company

an industrial engineer, and an environmental engineer. Members of this team had many years of marketing and forecasting experience. The team utilized published data, the open literature, contacts with trade associations and individual industries, and other proprietary sources in acquiring the necessary body of information.

In many cases, excellent sources of data were found, but in others it was hard to locate and verify data. Thus it sometimes became necessary to make first estimates for a given SIC and later to revise these as better data became available. Certainly the quality of the data on the known or suspected uses of mercury is variable, but because of the rigorous materials balance procedure followed, we estimate that most of the values used are within plus or minus 30 percent of actual, and in many cases are much better.*

Inputs on the quantity of mercury entering the economy in 1973 were of course based on the Bureau of Mines data, which are the best available.** In determining the sources of mercury from Sectors I, II, III, and V for specific facilities such as mines, power plants, and manufacturing plants, a number of industrial sources provided much of the necessary information on location and production. These varied sources included the Bureau of Mines Mineral Yearbook, SRI's Chemical Economics Handbook, the Directory of Chemical Producers, and the magazines Chemical Week and Chemical Marketing. Where conflicting information was encountered (which happened frequently) the best judgment of the team was exercised. Where the number of facilities was excessive (greater than 50), as for example paint manufacturers, Census of Manufacturers' data were used on a state-by-state basis. In all cases the production of a designated facility was used as a basis for estimating mercury uses and losses; all values were reported in terms of mercury metal. As an example, a materials balance for coal usage in the United States is shown in Figure 8. It indicates total usage (input) of 73,923 kg of mercury, with detailed losses (output) to the environment thereafter. This chart was derived from a large variety of sources as well as from Bureau of Mines data (Ref. 23) and assumes an average mercury content of 0.16 ppm. Similarly, a materials balance for any fossil fuel for any state or group of states can be made based upon these same data, with adjustments for the 1973 base.

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* Some sources of information initially considered to be most useful were soon found to be of little or no value. For example, permit application lists of potential mercury emitters (based on RAPP data) by EPA region were found to contain spurious data, or data which could not be validated. We suspect that much of the data was recorded in the wrong units.

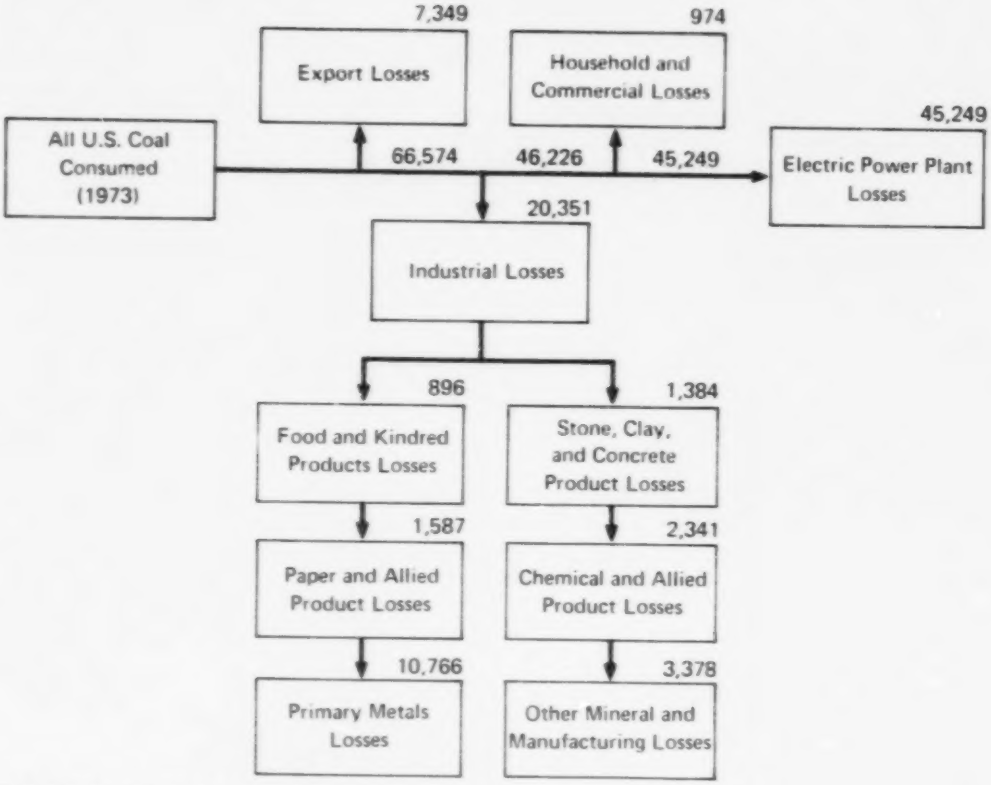
** It is true the Bureau of Mines data have some shortcomings in that they are derived from proprietary reports submitted by industry. Thus there may be small errors in reporting use category. However, on the input end, only secondary mercury is subject to such error, so overall, the input data are considered exceptionally reliable.

Two categories have been identified which are amenable to either a case-by-case study or to the use of regional statistics. Discharges in the first category are termed "point source emissions" and include mines, smelters, chlor-alkali plants, other chemical plants that manufacture mercurials, battery manufacturers, etc. For the second category, a number of "area source emissions" were identified in the final consumption sector. For example, dental usage applies to the general population, industrial instruments can be applied to a very wide variety of manufacturing industries, and so on. Since it was not possible to trace down these very widespread uses, an equation which derives from national consumption figures was developed which allows us to estimate regional consumption, as follows:

$$\text{National consumption} \times \frac{\text{regional population}}{\text{national population}} = \text{regional consumption}$$

Population serves adequately as a factor for general consumer products such as dental preparations, drugs, batteries, and heating fuel. However, it does not adequately describe other types of consumption patterns which are related to commercial and industrial activity. Therefore, two other types of factors--a multifactor, and a manufacturing employment ratio--were developed.

The multifactor, which is based on population and on commercial and industrial activity, is used to determine a region's usage of mercury in commercial products (fluorescent lamps, nonfarm pesticides, laboratory items, paints, "other"). The manufacturing employment ratio is based on manufacturing activity (which can be either employment or manufacturing value added). This


7,349
Export Losses
974
Household and Commercial Losses
45,249
All U.S. Coal Consumed (1973)
66,574
46,226
45,249
Electric Power Plant Losses
20,351
Industrial Losses
896
1,384
Food and Kindred Products Losses
Stone, Clay, and Concrete Product Losses
1,587
2,341
Paper and Allied Product Losses
Chemical and Allied Product Losses
10,766
3,378
Primary Metals Losses
Other Mineral and Manufacturing Losses

SOURCE: URS Research Company.

Figure 8 MATERIALS BALANCE OF MERCURY FROM COAL IN THE UNITED STATES (kilograms)

ratio is used to determine a region's mercury usage for specific processes only (paint formulation, tubes/switches, control instruments).

Distribution of consumption within a study region can be further broken down to the county level, based upon the same criteria and factors as for the region. Emitters, however, by their very definition are diffuse and must be treated in the computer analysis as point sources. Hence they are assigned to a county or, in the latitude-longitude program (URSLL), they are assigned to the population center of that county.

The total amount of mercury available (PROD in the listing of inputs in Table 5), whether from an area or point source, must be assigned to an environmental recipient. A second equation applies here:

$$\text{Total mercury} \times \text{fraction available} \times \text{emission factor} \\ = \text{loss to environment}$$

The fraction of mercury available for use is normally 1.0, but it can be used to account for the mercury which remains in place (for example, as noted above, in dental use 75 percent is assumed to remain in the teeth indefinitely). The emission factor accounts for the fraction of mercury lost to the environmental recipient. As an example, Figure 8 showed that the total estimated mercury in coal used by electric utilities in 1973 was 45,249 kg, all of which was assumed to be available. The emission factors used to distribute this mercury are:

$EF_A = 0.9$ (air)
$EF_W = 0.0$ (water)
$EF_L = 0.1$ (land)
$EF_{RC} = 0.0$ (recycle)

Then the annual emissions to air nationwide are:

$$45{,}249 \text{ kg} \times 1.0 \times 0.9 = 40{,}724 \text{ kg}$$

In a similar fashion, the emissions to land can be found to be 4,525 kg (with nothing to water or recycling).

Emission factors for air, water, land, and recycle were in most cases based upon prior studies, especially Ref. 12. Those which could not be validated satisfactorily were researched further, and in some cases substantial changes were introduced.

Table 7 summarizes, for each sector and each SIC study:

- Total mercury available on a national basis, in thousands of kilograms
- The fraction of this mercury available
- Emission factors for each environmental recipient

Further information on the detailed methodology followed for each particular SIC is given in Appendix D.

Calculation of Contributions from Natural Sources

Degassing

The calculation of natural degassing rates was based on work performed by others and on observations and assumptions developed in this study. Various workers have developed both global and regional degassing rates (see Table 8). These observations and calculations indicate that (1) the average land degassing rate is probably 0.2 microgram per square meter per day ($\mu g/m^2/day$); (2) degassing rates higher than the average are associated with mineralized deposits; (3) because of biological and chemical activity, over igneous sediments high in mercury the degassing rate is probably higher than over land; (4) the ratio between global land and ocean degassing is unknown, but Mackenzie and Wollast's assumption of equality (Ref. 26) is probably adequate. Using these concepts of degassing, URS calculated a probable national degassing rate. Assumptions on which these calculations were based are summarized below:

1. The base national degassing rate was assumed to be 0.2 $\mu g/m^2/day$.
2. For moderately mineralized areas a degassing rate of 0.4 $\mu g/m^2/day$ was assumed.

TABLE 7. - Emissions and Emission Factors for Mercury, by SIC and Sector

Sector	SIC	Description	Kg(x 10^3) of Hg Available^a	Fraction of Available Hg Lost^b	Emission Factors for			
					Air	Water	Land	Inventory and Recycle
I	1092M	Mercury Mining	0.02	1.00	0.20	0.10	0.70	-
	1092P	Mercury Processing^c	8.8	1.00	0.95	-	0.05	-
II	1021	Copper Mining	0.11	1.00	0.20	0.10	0.70	-
	1031	Zinc and Lead Mining	0.02	1.00	0.20	0.10	0.70	-
	3331	Copper Smelting	45.3	1.00	0.90	0.05	0.05	-
	3332	Lead Smelting	5.3	1.00	0.90	0.05	0.05	-
	3333	Zinc Smelting	5.1	1.00	0.90	0.05	0.05	-
	3241	Cement Processing	2.6	1.00	0.20	0.10	0.70	-
	3274	Lime Processing	0.5	1.00	0.20	0.10	0.70	-
III	021	Livestock	36.3	0.97	-	-	0.50	0.50
	2911C	Fuel Oil	17.1	1.00	0.999	-	0.001	-
	2911M	Refineries	2.4	1.00	0.50	-	0.50	-
	2951C	Tars and Asphalt	17.8	1.00	0.06	0.09	0.85	-
	3312M	Coke Ovens	10.2	1.00	0.70	0.05	-	.25
	4091C	Coal	11.2	1.00	0.90	-	0.10	-
	49110	Utilities - Oil & Gas Burning	12.1	1.00	0.999	-	0.001	-
	4924C	Natural Gas - Res., Comm., Ind.	6.0	1.00	0.999	-	.001	-
	4911C	Utilities - Coal Burning	45.3	1.00	0.90	-	0.10	-
V	2.5B	Caustic	9.5^d	1.00	-	.80	.20	-
	2819M	Catalyst						
	2851M	Paint	348.5^e	0.001	0.05	0.90	0.05	-
	2879M	Pesticides						
	2833M	Pharmaceutical Manuf.	20.9	0.001	0.05	0.90	0.05	-
	2812	Chlor-Alkali	452.4	1.00	0.035	.004	0.501	0.46
	2261	Textiles	7.8	1.00	-	0.02	0.98	-

TABLE 7 - Emissions and Emission Factors for Mercury, by SIC and Sector (continued)

Sector	SIC	Description	Kg(x 10^3) of Hg Available	Fraction of Available Hg Lost[b]	Emission Factors for			
					Air	Water	Land	Inventory and Recycle
V	2851F	Paint Formulation	247.7	0.65	0.45	0.55	-	-
	38291M	Control Instrument Manuf.	196.8	0.01	-	-	1.00	-
	3079P	Vat Dyes	7.8	0.001	0.5	0.90	0.05	-
	3.0	Other	69.2	1.00	0.15	0.15	0.40	0.30
	36292M	Tubes/Switches Manuf.	63.3	0.025	-	-	1.00	-
	36410M	Lamp Manuf.	46.6	0.04	0.05	-	0.95	-
	36420M	Battery Manuf.	563.6	0.005	0.05	0.02	0.93	-
VIIIA	2.5A	Urethane[f]	15.6	0.15	0.05	-	0.95	-
	2879C	Nonagric. Pesticides	44.0	1.00	0.10	0.40	0.50	-
	2879F	Agric. Pesticides	19.1	1.00	-	0.15	0.85	-
	38291C	Control Instrument Cons.	206.9	1.00	0.04	-	0.56	0.40
	36292C	Tubes/Switches Cons.[f]	53.9	1.00	0.05	-	0.95	-
	36410C	Lamp Cons.[f]	43.4	1.00	0.05	-	0.95	-
	7391	Laboratory	22.7	1.00	0.10	0.26	0.07	0.57
VIIIB	2834C	Pharmaceutical Cons.	20.9	1.00	-	1.00	-	-
	2851C	Paint. Cons.	247.1	0.70	0.95	-	0.05	-
	36420C	Battery Cons.[f]	497.0	1.00	0.05	-	0.90	0.05
	8021	Dental	92.3	0.25[g]	0.04	0.72	-	0.24

a. Amount of mercury available on a national basis within the given SIC.

b. Fraction of available mercury that is lost to air, land, or water, or that is recycled or remains as part of an in-plant inventory.

c. Includes secondary processing.

d. Based on 3.7 ppm mercury concentration in caustic sold in 1973.

e. This total represents all the mercury used in the manufacture of organic and inorganic compounds that will be incorporated in paint and pesticides and used as catalysts.

f. Emissions to air, land, and water are based on the proportion of solid waste incinerated. On a national average, this is about 5 percent.

g. The remaining 75 percent stays in the teeth and is considered unavailable.

Source: URS Research Company

TABLE 8. - Natural Degassing Rates Calculated by Various Workers

Source	Ref. No.	Degassing Rate ($\mu g/m^2$/day)	Remarks
Kothny	24	4.0 (Franciscan soils) 0.8 (normal soils)	Calculated on the basis of an apparent increase in regional ambient air concentration as the air mass moves across Western California.
Weiss	8	0.5	Calculated from the total global atmospheric burden (based on global concentration) and the average global turnover time (10 days). Emissions were assumed to occur only over land.
Erickson	25	10.0	Same calculation method as Weiss, but assumed background concentration of 20 $\mu g/m^3$ and about 150 days turnover time.
Mackenzie and Wollast	26	0.5	Used Weiss's number but assumed degassing rates over air and land are equal.
Anderson et al.	1	0.0014	Same calculation procedure as Weiss but assumed background concentrations of 0.5 $\mu g/m^3$.
McCarthy et al.	18	0.064 - 41.86 0.2 (natural background)	Measured degassing rate from both mineralized and unmineralized areas.

Source: Compiled by URS Research Company

3. For highly mineralized areas and known mercury deposits a rate of 0.8 μg/m^2/day was assumed.

For the purposes of differentiating between areas, Figure 9, which indicates general areas of known mercury and mineralized deposits, was used. Using the degassing rates shown above and the total surface area (both land and water for each state), a state-by-state inventory of total annual degassing was made. On a national basis, the annual degassing rate was estimated, on the basis of 0.36 μg/m^2/year, to be about 1 million kg per year.

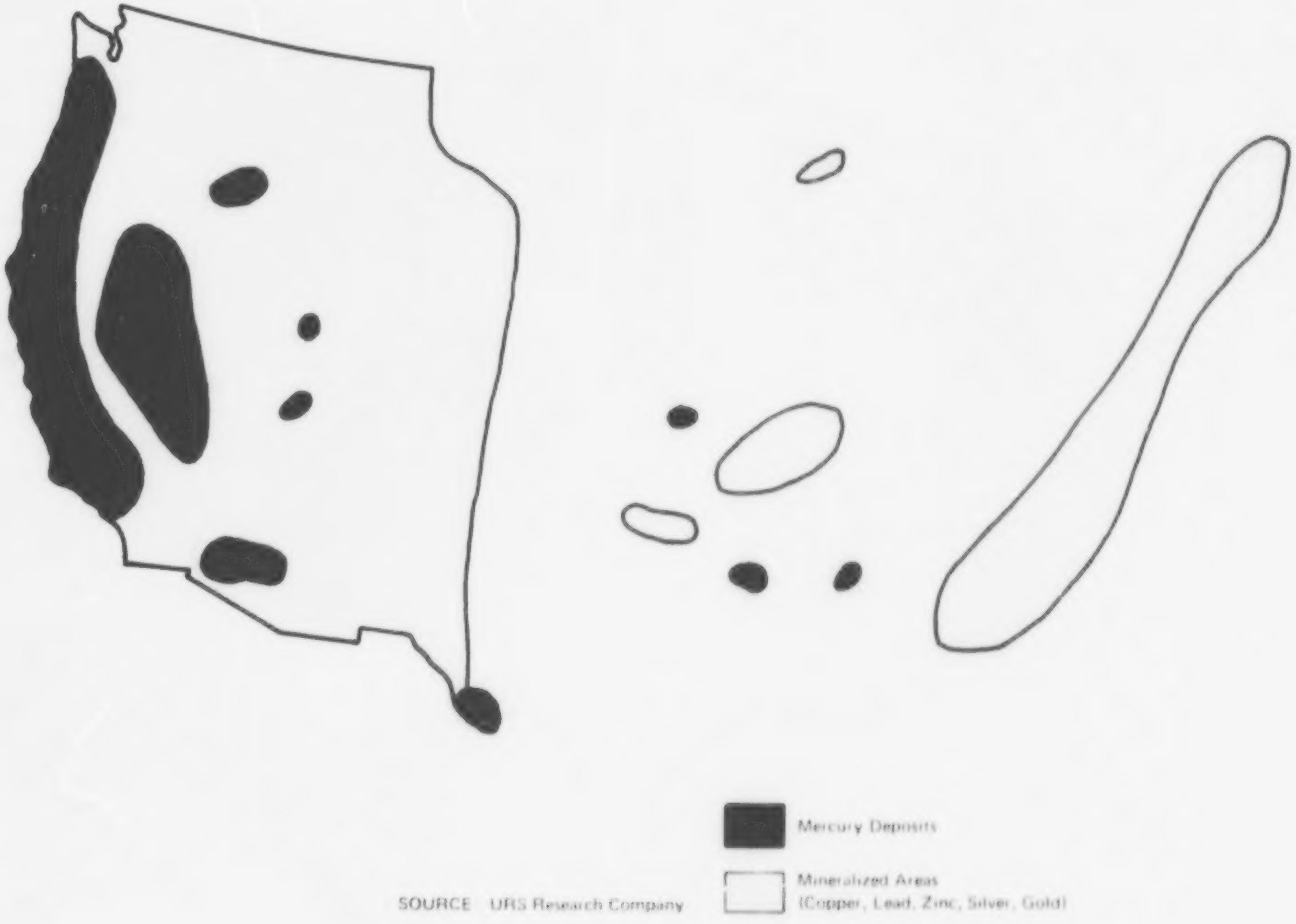
Runoff

The other natural source contribution, that of erosion, was determined by calculating the average annual runoff from each state (Ref. 27) and multiplying this figure by the average statewide sediment concentration (Ref. 28). The total annual sediment load was then multiplied by the average sediment mercury concentration of 71 ppb (Ref. 29). The state totals were then summed for the national inventory, for an overall total of about 200,000 kg per year. An attempt was also made to determine the contribution from urban runoff. According to this calculation, urban runoff contributes about 10,000 kg per year to the nation's waters, or about 5 percent of the soil erosion total.

Contributions from Final Disposal

Sewage

In determining mercury losses to air, land, and water from sewage treatment plants, the initial assumption was that the overall sewage generation rate for sewered communities was 100 gallons per capita per day (gpcd) and that the rate for areas served by septic tanks was 75 gpcd. The population percentages served by community sewer systems and septic tanks were found in the U.S. Census of Housing (Ref. 30). The per capita generation rates were then multiplied by the specific study area population in question to estimate the sewage flow.


Mercury Deposits
Mineralized Areas
(Copper, Lead, Zinc, Silver, Gold)

SOURCE URS Research Company

Figure 9 MINERALIZED AREAS AND MERCURY DEPOSITS IN THE UNITED STATES

For each study area, an influent concentration of 2.0 ppb (Ref. 12) and a removal efficiency of 50 percent (Refs. 31, 32) was assumed. By multiplying together the estimated total flow, the assumed influent concentration, and a series of conversion factors, the total annual amount of mercury flowing into the typical sewage treatment plant was determined.

The environmental receiving medium (air, land, or water) of this mercury was calculated by multiplying the total annual amount of mercury reaching the plant by the percentage of the effluent lost to land or water and sludge landfilled or incinerated. These percentages were derived from the latest national inventory of municipal treatment plants, which lists the effluent and sludge disposal practices for each plant in the nation (Ref. 33).

Groundwater

Very little information is available on the mercury concentration of groundwater; the most widely quoted value is 0.05 ppb (see Refs. 2, 34, 35). This is a reasonable figure because the generally high adsorptive capacity of soils should reduce mercury concentrations as water containing mercury percolates to the water table.

Quantities of groundwater withdrawn in a given region were taken from U.S. Geological Survey (USGS) publications for individual states; USGS data were also used for national figures (Ref. 36). The yearly quantity of mercury was determined by applying a list of conversion factors to the average mercury concentration and quantity of groundwater withdrawn.

RESULTS

Tables 9 through 13 summarize the mercury emission data for each study region. These tables and the discussion to follow point out the significant contributors of mercury to the environment.

These tables have been designed to present the major results of each regional inventory in a concise form, while still providing the reader with an overview of important findings. At the far left of each table are listed the sectors, which correspond to the sectors of the I/O model (Fig. 7) and which are described in Table 4. In the next column are the sector names, with important contributors within each sector. Since all results are reported on a sector basis rather than as individual SIC contributors, the fraction each SIC contributes to the total emissions of a sector is shown in parentheses in this column. For example, in Table 9 under Sector V, paint manufacture accounts for 4 percent of the total emissions (1,839 kg) of that sector. The next three columns indicate emissions (in both kilograms and pounds) to air, water, and land, from each sector, with the fourth column showing the totals. A final column indicates the amount of recycling associated with the sector. Only recycling which extends beyond plant limits is considered. Thus, for example, recycle of rejected batteries in a manufacturing facility is not included. Emissions to air, water, and land are summed under "Totals" in the row following Sector VIIIB, indicating, for the region, total losses to these three environments from man-related sources. (These totals, of course, include mercury introduced into commerce as well as that from unregulated sources.) The totals have been used to calculate the fraction each sector contributes to the given environment (shown in each column). (For example, in Table 9 the total emissions to water are 2,666 kg; for Sector V the contribution to water is 584 kg--or 22 percent of the total, as shown parenthetically.) A similar percentage has been derived for the total column also.

Below the totals and under the heavy line are figures for the two other identifiable sources of mercury--final disposal and natural sources. Final disposal, which includes sewage treatment plants and landfills, is not included as part of the man-related inputs, in order to avoid double accounting. In the case of landfills no values have been listed, but it is assumed that virtually all emissions to land from Sectors V, VIIIA, and VIIIB will be deposited in either industrial or public landfills. Similarly, in the case of water, most of the emissions from these same sectors will find their way into public sewage treatment plant influents. We estimated the mercury content of sewage influents independently, and these values have been included, as have estimates on the disposal of the resultant mercury-bearing sludge to either landfills or to incineration (see Section IV for additional detail). On the assumption that most water-borne mercury wastes are directed to sewage influents, we presumed that the independent estimate of the mercury content of sewage would agree, within limits, with the emissions determined by our inventory results. In Table 9 this is the case; that is, we estimate the emissions from Sectors V, VIIIA, and VIIIB to be 2,605 kg and 1,679 kg was the independent estimate--in reasonable agreement. However, this agreement was not found for the other study regions. We conclude that the error (if it is an error) is largely in the estimate of the mercury content of sewage influents; the values were obtained from many sources and the sampling and analytical techniques used were in many cases open to question.

Each table includes estimates of the magnitude of three natural sources--degassing from the earth's crust, surface runoff, and release through underground waters. The derivation of these estimates was discussed previously; it was noted in that discussion that these are "best estimates," based upon rather sketchy data (and in the case of degassing on tentative hypotheses). We have, however, used conservative estimates in all cases. The totals for natural sources do not include any man-related sources of mercury and it can be assumed that the natural sources are not controllable to any degree by man.

Regional Analyses

The following paragraphs present a brief overview of the findings for each study region and discuss the implications of these findings.

California Study Region

As indicated in Table 9, three sectors (I, VIIIA, and VIIIB) account for virtually all of the mercury losses in this region. These findings are consonant with the characteristics of the region, which has relatively little heavy industry (and contains no mercury or mercurial manufacturers or processors) but which does contain a fair amount of agricultural activity and which is the only active mercury mining region in the nation at the present time. Looking

TABLE 9. - Mercury Emissions to the Environment in the California Study Region

Sector		Air	Water	Land	Total	Recycle
I	Mercury Mining & Smelting (1.0) Imports (0.0) Recycling (0.0)	3,795 kg (8,360 lb) (34.6%)[a]	5 kg (10 lb) (0.2%)[a]	232 kg (510 lb) (1.1%)[a]	4,032 kg (8,880 lb) (11.5%)[b]	--
II	Other Mining Copper (0.80) Lime (0.10) Cement (0.10)	14 kg (30 lb) (0.1%)	9 kg (20 lb) (0.3%)	68 kg (150 lb) (0.3%)	91 kg (200 lb) (0.3%)	--
III	Unregulated Sources Livestock (0.17) Fossil Fuels, Comm. & Ind. (0.46) Household (0.35) Electric Power (0.08)	913 kg (2,010 lb) (8.3%)	45 kg (100 lb) (1.7%)	676 kg (1,490 lb) (3.2%)	1,634 kg (3,600 lb) (4.7%)	--
V	Manufacturing & Processing Chlor-Alkali (0.00) Paint Mfr. (0.04) Foam-Caustic (0.23) Other (0.77)	195 kg (430 lb) (1.8%)	586 kg (1,290 lb) (22.0%)	1,058 kg (2,330 lb) (5.0%)	1,839 kg (4,050 lb) (5.3%)	409 kg (900 lb)
VIIIA	Final Consumption: Comm. & **Industrial** Lamps (0.06) Controls/Instr. (0.29) Tubes/Switches (0.37) Laboratory (0.12) Pesticides (0.16)	300 kg (660 lb) (2.7%)	468 kg (1,030 lb) (17.5%)	6,229 kg (13,720 lb) (29.2%)	6,997 kg (15,410 lb) (20.0%)	3,682 kg (8,110 lb)
VIIIB	Final Consumption: Consumer Goods Pharmaceuticals (0.03) Paint (0.31) Batteries (0.63) Dental (0.03)	5,739 kg (12,640 lb) (52.4%)	1,553 kg (3,420 lb) (58.3%)	13,066 kg (28,780 lb) (61.3%)	20,358 kg (44,840 lb) (58.2%)	922 kg (2,030 lb)
	Totals	10,956 kg (24,130 lb)	2,666 kg (5,870 lb)	21,329 kg (46,980 lb)	34,951 kg (76,980 lb)	5,013 kg (11,040 lb)
	FINAL DISPOSAL					
	Sewage	54 kg (120 lb)	876 kg (1,930 lb)	749 kg (1,650 lb)	1,679 kg (3,700 lb)	
	Landfill	----------------------------Unknown--------				
	NATURAL SOURCES					
	● Degassing				26,900 kg (59,300 lb)	
	● Runoff				5,200 kg (12,700 lb)	
	● Groundwater				270 kg (600 lb)	

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a. Emission by sector as a percent of total emission to air (or water or land).

b. Percent of all emissions by sector to all emissions in the study region.

c. An estimated one-third (including mercury metal) is in soluble form; remainder moves rapidly into sediments.

Source: URS Research Company

further at mercury mining and smelting (Sector I), it can be seen that these sources alone accounted for almost 35 percent of the total emissions to air; considering the depressed state of the mercury mining industry in the subject year (1973) it can be seen that if mining activity were greatly increased, the Sector I emissions would be even more important in the overall picture. However, it should be noted that the mercury mining activity in the study region at the present time is conducted in very remote areas and is likely to have little impact on populated centers. (The one exception is the New Almaden Mine, which is adjacent to the San Jose metropolitan area but which is now being phased out of operation.)

Contributions from miscellaneous mining and processing (Sector II) were trivial, and even those from unregulated sources (Sector III) were surprisingly low. In this sector, emissions related to livestock manure were only marginal (despite a rather extensive livestock industry in the Central Valley) and emissions related to fossil fuel usage were small. These low emissions from fossil fuel usage are to be expected, however, since the study region uses natural gas (with low mercury content) for most residential and commercial uses, and for steam-electric power generation. Since the energy "crunch" has developed, boilers using only natural gas have generally been converted to dual usage--natural gas or fuel oil--with increasing reliance on fuel oil. The use of coal, with its relatively high mercury content, is virtually unknown in the region.

The contributions from the final consumption sectors (VIIIA and VIIIB) accounted for most of the man-related losses in the region, and were quite typical for this sector. These losses were primarily to landfills (incineration of solid wastes is not practiced in the region) which are well regulated, ensuring that movement of mercury from the final disposal sites is minimal.

The region was found to contribute above-average quantities of mercury to the air from degassing of the earth's crust. The region consists of mercuriferous soils in general, and is therefore estimated to degas at about two times the national average, resulting in emissions to air estimated at 26,900 kg annually--about two and one-half times higher than the total man-made emissions to air. Runoff (primarily from mercuriferous soils) was about two times higher than were man-related water discharges. Groundwater usage is relatively high in some parts of the region, but groundwater is very low in mercury content and contributed little.

Two potential sources of mercury were initially considered: (1) the fumaroles and geysers in the region, and (2) the spent mercury used during the Gold Rush days in the amalgamation of gold. However, neither of these sources proved to be important. Steam from the geysers, which is currently being used commercially by the local electric utility, was found to contain low concentrations of mercury, as was runoff associated with the geysers. (The geysers are surrounded by abandoned mercury mines, but of course their source of steam is far below ground.)*

It has been estimated that millions of flasks of mercury were mined and used in processing gold in the early days of California. Even today it is reported that, in digging among the gold tailings, metallic mercury may be uncovered. However, we were unable to find any substantive data which indicated that this residual mercury impinges in any way on man or his food chain. We hypothesize that most of this mercury has either been leached away or has vaporized over the intervening century.

Arizona Study Region

The State of Arizona was chosen for study primarily because of its significant copper mining and processing industry. Copper ores contain mercury in trace quantities, and this mercury is released during the smelting process. From Table 10, it is evident that copper smelting operations are the major contributors to the air and water emissions in this region. Nevertheless, the copper industry poses no significant or even appreciable hazard in terms of adverse health effects. Smelter emissions do lead to ambient mercury levels in air which are substantially above background but well below levels considered deleterious to health.

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* Some geyser activity and much volcanic activity have high mercury content; however, the quantities emitted are low, except for extreme volcanic activity, and in general cannot be considered to be important mercury contributors to the natural environment.

TABLE 10. - Mercury Emissions to the Environment in the Arizona Study Region

Sector		Air	Water	Land	Total	Recycle
I	Mercury Mining & Smelting	--	--	--	--	--
II	Copper Mining & Smelting Copper Mining (0.004) Copper Smelting (0.996)	19,622 kg (43,168 lb) (84.3%)[a]	1,088 kg (2,393 lb) (53.8%)[a]	1,119 kg (2,461 lb) (12.8%)[a]	21,829 kg (48,022 lb) (64.2%)[b]	--
III	Unregulated Sources Livestock (0.06) Fossil Fuels; Res., Comm. & Ind. (0.92) Elec. Utilities (0.02)	705 kg (1,552 lb) (3.0%)	144 kg (316 lb) (7.1%)	433 kg (953 lb) (5.0%)	1,282 kg (2,821 lb) (3.8%)	--
V	Manufacturing and Processing Foam Caustic (0.20) Other (0.80)	114 kg (251 lb) (0.5%)	127 kg (280 lb) (6.3%)	385 kg (847 lb) (4.4%)	626 kg (1,378 lb) (1.8%)	144 kg (317 lb) (7.6%)
VIIIA	Final Consumption: Comm. & Industrial Lamps (0.07) Controls/Instr. (0.29) Tubes/Switches (0.47) Laboratory (0.09) Pesticides (0.08)	20 kg (44 lb) (0.0%)	96 kg (211 lb) (4.7%)	2,055 kg (4,520 lb) (23.6%)	2,171 kg (4,775 lb) (6.4%)	1,552 kg (3,414 lb) (82.3%)
VIIIB	Final Consumption: Consumer Goods Pharmaceuticals (0.03) Paint (0.34) Batteries (0.52) Dental (0.11)	2,825 kg (6,216 lb) (12.2%)	568 kg (1,249 lb) (28.1%)	4,723 kg (10,390 lb) (54.2%)	8,116 kg (17,855 lb) (23.8%)	190 kg (417 lb) (10.1%)
	Totals	23,286 kg (51,231 lb)	2,023 kg (4,449 lb)	8,715 kg (19,171 lb)	34,024 kg (74,851 lb)	1,886 kg (4,148 lb)
	FINAL DISPOSAL					
	Sewage	23 kg (51 lb)	227 kg (499 lb)	278 kg (594 lb)	528 kg (1,144 lb)	
	Landfill	------------------------	Unknown	------------		
	NATURAL SOURCES					
	o Degassing				84,400 kg (192,200 lb)	
	o Runoff				5,600 kg[c] (12,400 lb)	
	o Groundwater				296 kg (652 lb)	

a. Emission by sector as a percent of total emission to air (or water or land).
b. Percent of all emissions by sector to all emissions in study region.
c. An estimated one-third (including mercury metal) in soluble form; remainder moves rapidly into sediments.

Source: URS Research Company

Most of the major copper smelters are located some 40 to 100 miles east of the two major metropolitan areas, Phoenix and Tucson. The prevailing winds are from the east, so the Phoenix and Tucson areas could be exposed to mercury emissions. However, diffusion modeling results indicate that the amounts of mercury reaching highly populated areas would be trivial. (Further discussion of this hazard is included in Section IV.)

The region displayed no unusual anomalies with respect to emissions from other sectors. However, the state has many ore deposits; as discussed elsewhere, these are a source of mercury via degassing and contribute heavily to the total quantity of 84,400 kg emitted in the region. The total emissions to air from natural sources are four times higher than those from man-related sources. The mercury content of runoff is unusually low, chiefly because the region is so arid. Because of the highly variable flow rates of the few streams in the state (which are dry much of the year), the probable fate of mercury in sediments may well be different from that in streams that maintain flow the year around. This point was not investigated, however.

Kentucky/Tennessee Study Region

This study region contains a number of large, coal-fired power plants of the Tennessee Valley Authority (TVA). Table 11 shows that almost 45 percent of the total mercury emissions to air are due to Sector III sources, and that the bulk of the Sector III contribution comes from the utilities plants. However, despite the large volume of mercury from these sources, the resultant ground level concentrations of mercury vapor are very small--in fact, the levels are not much greater than that contributed by natural background.

This area also contains two chlor-alkali plants which account for more than 90 percent of the Sector V emissions. Manufacture of various electrical apparatus, and catalyst use, which initially were thought to contribute significantly to the mercury loss in this region, proved to be only minor sources.

By discounting the losses assigned to the chlor-alkali plants in the region (whose major losses are to industrial landfills), a truer picture of other losses can be obtained. Without chlor-alkali losses, man-related

TABLE 11. - Mercury Emissions to the Environment in the Kentucky/Tennessee Study Region

Sector		Air	Water	Land	Total	Recycle
I	Mercury Mining & Smelting	-	-	-	-	-
II	Other Mining & Smelting Zinc Mining (0.01) Copper Smelting (0.99)	257 kg (566 lb) (1.0%)[a]	14 kg (31 lb) (0.5%)[a]	14 kg (31 lb) (0.0%)[a]	285 kg (628 lb) (0.5%)[b]	-
III	Unregulated Sources Livestock (0.02) Electric Utilities (0.71) Natural Gas (0.04) Tars and Asphalt (0.10) Refineries (0.00) Fuel Oil (0.02) Coal (0.11) Fuel Reprocessing (0.00)	9,114 kg (20,050 lb) (44.5%)	120 kg (264 lb) (4.0%)	2,112 kg (4,646 lb) (4.0%)	11,346 kg (24,960 lb) (16.0%)	-
V	Manufacturing & Processing Foam-Caustic (0.01) Catalysts (0.01) Other (0.07) Chlor-Alkali (0.91) Paint (0.00)	2,428 kg (5,341 lb) (12.0%)	857 kg (1,885 lb) (27.5%)	20,620 kg (45,364 lb) (44.0%)	23,905 kg (52,590 lb) (34.0%)	458 kg (1,009 lb) (6.0%)
VIIIA	Final Consumption: Commercial and Industrial Lamps (0.06) Controls/Instr. (0.27) Tubes/Switches (0.43) Laboratory (0.05) Pesticides (0.16) Foam/Plastics (0.03)	100 kg (220 lb) (0.5%)	530 kg (1,165 lb) (17.0%)	9,600 kg (21,120 lb) (21.0%)	10,230 kg (22,505 lb) (14.5%)	6,589 kg (14,495 lb) (81.0%)
VIIIB	Final Consumption: Consumer Goods Pharmaceuticals (0.03) Paint (0.34) Batteries (0.59) Dental (0.04)	8,497 kg (18,694 lb) (42.0%)	1,585 kg (3,487 lb) (51.0%)	14,191 kg (31,220 lb) (31.0%)	24,273 kg (53,401 lb) (35.0%)	1,024 kg (2,252 lb) (13.0%)
	Totals	20,396 kg (44,871 lb)	3,106 kg (6,832 lb)	46,537 kg (102,381 lb)	70,039 kg (154,084 lb)	8,071 kg (17,756 lb)
	FINAL DISPOSAL					
	Sewage				1,691 kg (3,720 lb)	
	Landfill	--------------------Unknown--------------------				
	NATURAL SOURCES					
	o Degassing				15,300 kg (33,700 lb)	
	o Runoff				7,400 kg[c] (16,200 lb)	
	o Groundwater				32 kg (70 lb)	

a. Emission by sector as a percent of total emission to air (or water or land).
b. Percent of all emissions by sector to all emissions in the study region.
c. An estimated one-third (including mercury metal) is in soluble form; remainder moves rapidly into sediments.

Source: URS Research Company

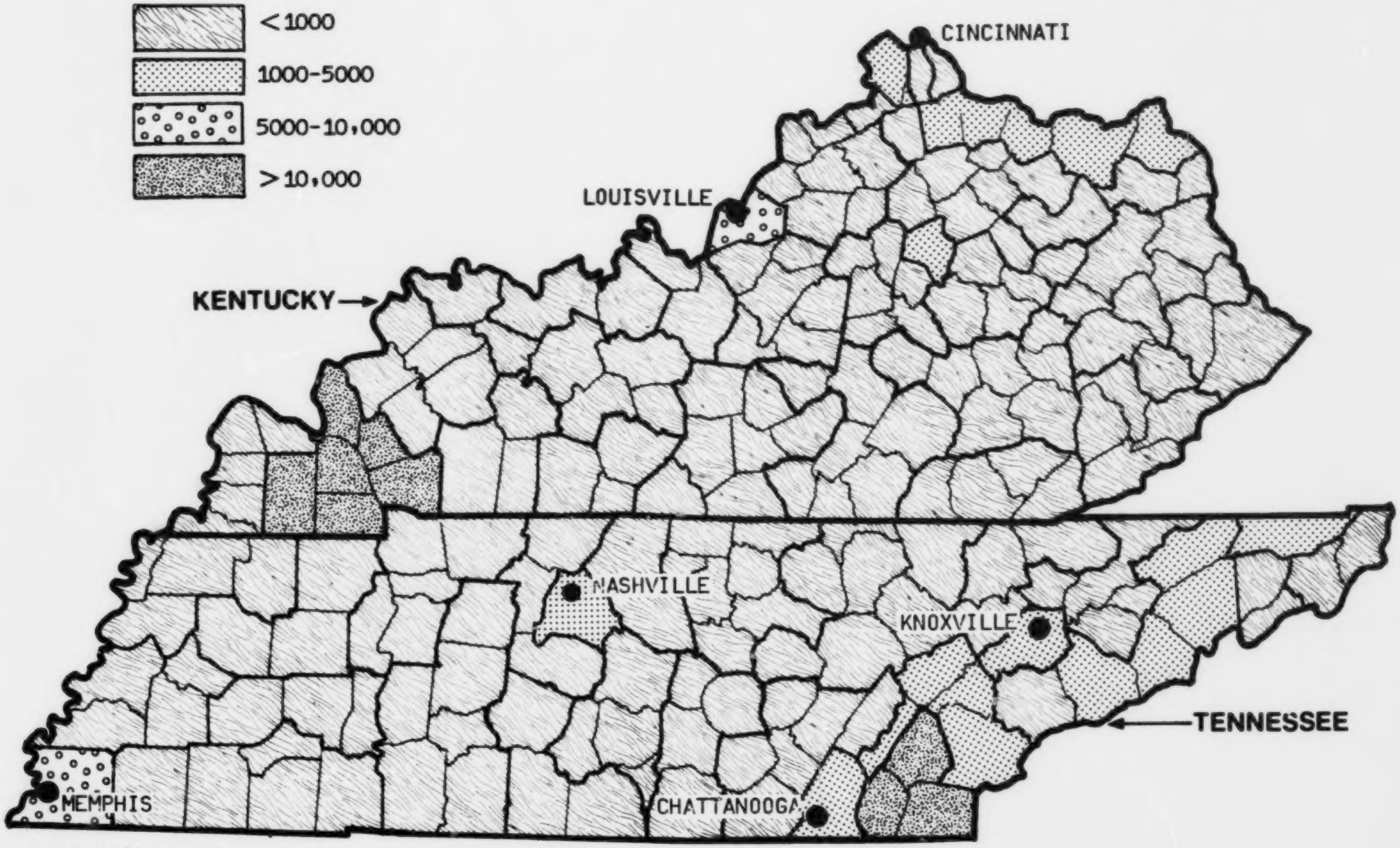
emissions to air account for almost 38 percent of all emissions; these air emissions are almost entirely from the coal-burning power plants (Sector III). (However, the quantities involved are still far less than those emitted by degassing, even though a degassing rate about one-fifth of that for California and Arizona study regions was assumed.) The large TVA coal-burning power plants are in most cases located in or are contiguous to populated areas. However, our analyses indicate that ground level concentrations are well within safe standards. The added load of some 7,000 kg to the global burden is, of course, another matter.

The Kentucky/Tennessee region was also analyzed on a county-by-county basis. This analysis was carried out only for emissions to land and air, as losses to water in the area are quite small, because of the rigorous standards in effect for mercury discharges into this medium.

Figures 10 and 11 show where the greatest losses of mercury are occurring in the Kentucky/Tennessee region. As would be expected, losses to land are most substantial where population density is the highest, particularly near Louisville and Memphis. The probable major source of these emissions is disposal to landfills. The high values in southwestern Kentucky and southeastern Tennessee (see Fig. 10) are due to chlor-alkali plant sludges that are disposed of in landfills. Nashville, Chattanooga, Knoxville, and northern Kentucky are high population centers where significant amounts of mercury are lost to land, primarily from battery disposal but also from disposal of mercury-containing lamps, tubes/switches, and control instruments.

Figure 11 is a graphic summary of air emissions for the region. Most of the emissions are from Kentucky, where the greatest number of large power plants are located, as well as two chlor-alkali facilities. Note that the highest emissions are adjacent to areas of greatest population (e.g., Memphis, Louisville, Nashville, and Knoxville).

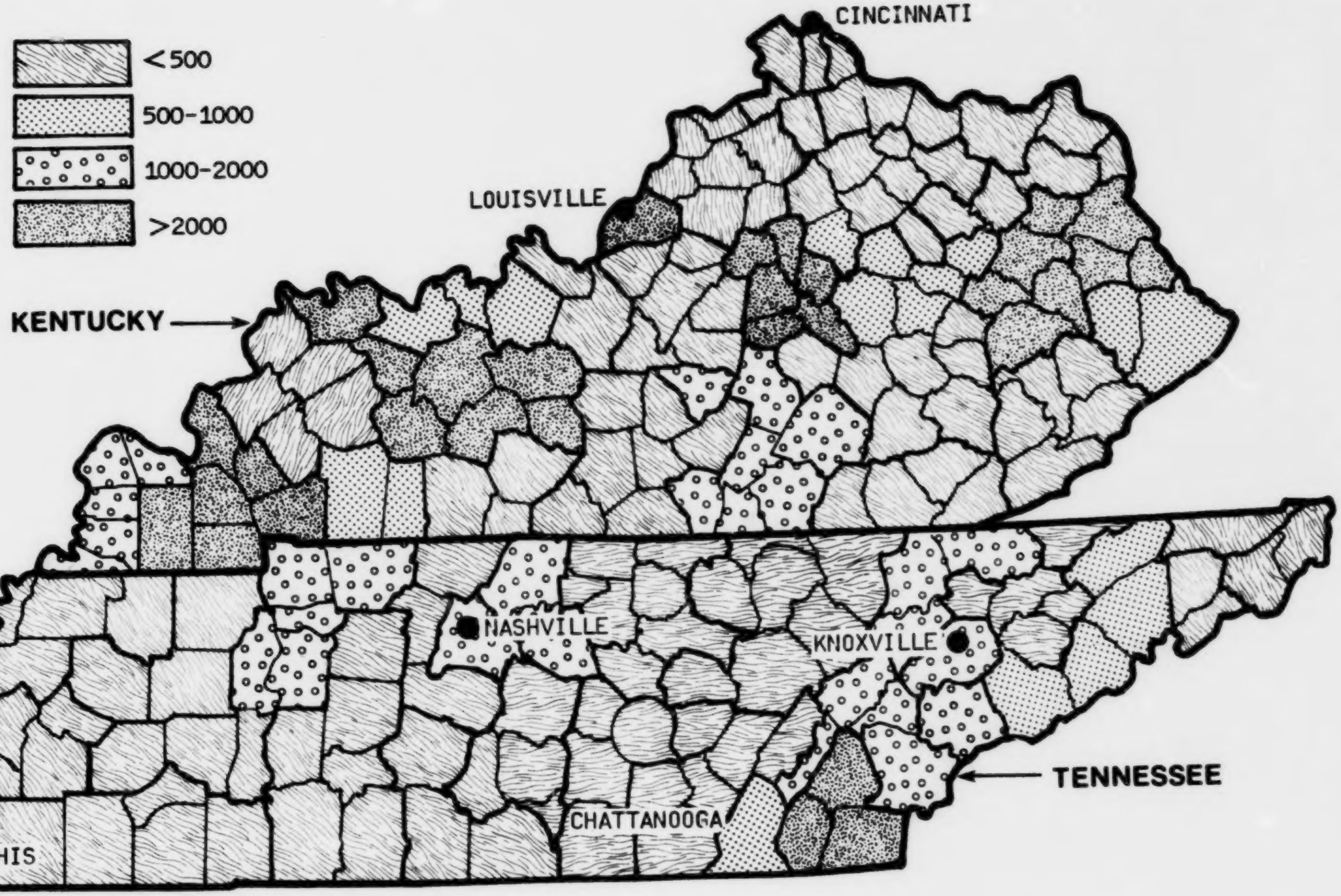
In order to determine where mercury losses are occurring in areas that do not conform to political boundaries, a portion of the Tennessee River between Knoxville and Chattanooga was chosen for analysis. The area was arbitrarily broken up into five "boxes," each covering approximately 250 square miles (see Fig. 12). Boxes 1 and 5 surround the metropolitan areas of Knoxville and



▨ <1000
1000-5000
5000-10,000
>10,000
CINCINNATI
LOUISVILLE
KENTUCKY
NASHVILLE
KNOXVILLE
TENNESSEE
MEMPHIS
CHATTANOOGA

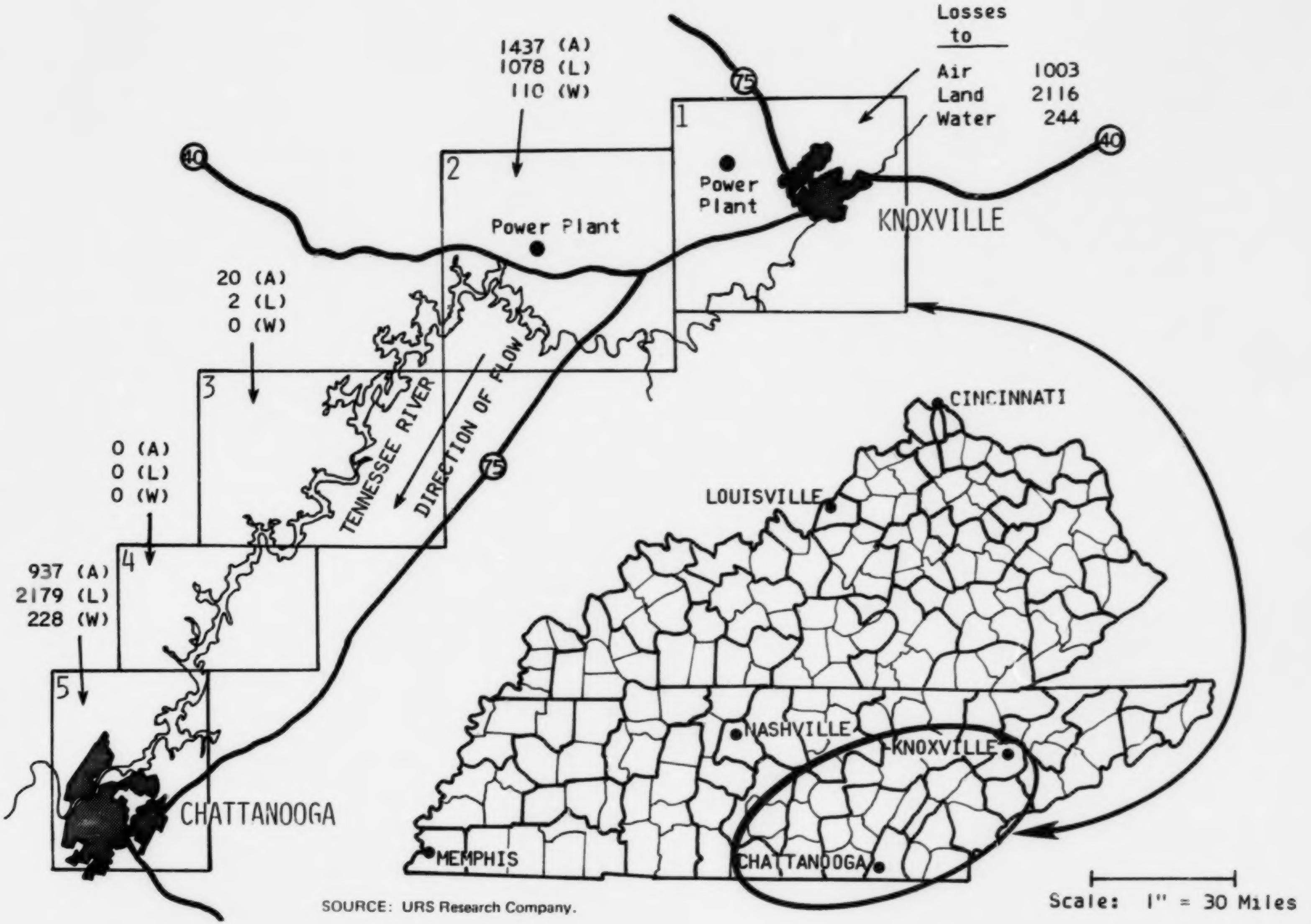
SOURCE: URS Research Company.

Figure 10 MERCURY EMISSIONS TO LAND IN KENTUCKY/TENNESSEE STUDY REGION, BY COUNTY, 1973 (pounds)


<500
500-1000
1000-2000
>2000
CINCINNATI
LOUISVILLE
KENTUCKY
NASHVILLE
KNOXVILLE
TENNESSEE
CHATTANOOGA
MEMPHIS

SOURCE: URS Research Company.

Figure 11 MERCURY EMISSIONS TO AIR IN KENTUCKY/TENNESSEE STUDY REGION, BY COUNTY, 1973 (pounds)


Losses
to
Air 1003
Land 2116
Water 244
1437 (A)
1078 (L)
110 (W)
20 (A)
2 (L)
0 (W)
0 (A)
0 (L)
0 (W)
937 (A)
2179 (L)
228 (W)
1
2
3
4
5
Power Plant
Power Plant
KNOXVILLE
CHATTANOOGA
TENNESSEE RIVER
DIRECTION OF FLOW
40
40
75
75
CINCINNATI
LOUISVILLE
NASHVILLE
KNOXVILLE
CHATTANOOGA
MEMPHIS
Scale: 1" = 30 Miles

SOURCE: URS Research Company.

Figure 12 LATITUDE/LONGITUDE ANALYSIS OF MERCURY EMISSIONS ALONG TENNESSEE RIVER, KENTUCKY/TENNESSEE STUDY REGION, 1973 (pounds)

Chattanooga, respectively. These two boxes account for most of the emissions to air, primarily because of the presence of power plants that use mercury-bearing coal for fuel.

No emissions are shown for Box 4, but this is not entirely accurate. Emissions that are based on either population, manufacturing employment, or a multifactor are represented by a point in the center of a county (or group of counties) and may not always be picked up in a "box" representing two points of longitude and two points of latitude. In contrast, specific emitters such as power plants, chlor-alkali plants, smelters, and manufacturers of consumer goods (e.g., batteries) can be so located.

Louisiana Study Region

This region was selected because it contains one of the largest petrochemical and oil refinery complexes in the nation. In support of this complex, several chlor-alkali plants are also located in the region; among these are three large mercury cell plants. As shown in Table 12, these three plants are the chief contributors of mercury emissions in the study region, particularly of emissions to land, which represent 79 percent of the total. However, these losses are to industrial landfills, which are normally lined with barrier material to ensure that the high water table in the state does not cause leaching problems. Thus the emissions can be considered as nonavailable to man's environment.

Aside from the chlor-alkali plant emissions, the unregulated discharges, which include those from industrial uses of natural gas (which are very high because the state is a major producer) and from refineries are important considerations, particularly with respect to air. However, the total quantities involved are relatively small, and it does not appear that petrochemical and refinery operations are of special concern.

Disregarding the chlor-alkali contributions, the final consumption sectors (VIIIA and VIIIB) are about on a par with those in the rest of the nation. Pesticides, primarily for nonagricultural applications, are important mercury emitters. Incineration is fairly widely practiced, so that mercury contributions to air (from Sector VIIIB in particular) are a bit above the national average.

TABLE 12. - Mercury Emissions to the Environment in the Louisiana Study Region

Sector		Air	Water	Land	Total	Recycle
I	Mercury Mining & Smelting	-	-	-	-	-
II	Other Mining & Smelting	-	-	-	-	-
III	Unregulated Sources Livestock (0.02) Electric Utilities (0.18) Nat. Gas - Industr. (0.42) Nat. Gas - Comm. and Res. (0.06) Tars and Asphalt (0.12) Refineries (0.13) Fuel Oil (0.07)	1,519 kg 3,343 lb) (21%)[a]	56 kg (124 lb) (6%)[a]	333 kg (733 lb) (1%)[a]	1,908 kg (4,200 lb) (5%)[b]	-
V	Manufacturing and Processing Foam-Caustic (0.01) Other (0.02) Chlor-Alkali (0.97)	2,855 kg (6,282 lb) (40%)	310 kg (683 lb) (32%)	27,838 kg (61,243 lb) (79%)	31,003 kg (68,208 lb) (71%)	125 kg (275 lb) (8%)
VIIIA	Final Consumption: Comm. & Industrial Lamps (0.08) Controls/Instr. (0.20) Tubes/Switches (0.31) Laboratory (0.10) Pesticides (0.31)	26 kg (57 lb) (0%)	163 kg (379 lb) (17%)	2,027 kg (4,460 lb) (6%)	2,216 kg (4,876 lb) (5%)	1,032 kg (2,269 lb) (68%)
VIIIB	Final Consumption: Consumer Goods Pharmaceuticals (0.02) Paint (0.32) Batteries (0.64) Dental (0.04)	2.753 kg (6,056 lb) (39%)	426 kg (937 lb) (45%)	5,114 kg (11,251 lb) (14%)	8,293 kg (18,244 lb) (19%)	367 kg (808 lb) (24%)
	Totals	7,153 kg (15,738 lb)	955 kg (2,103 lb)	35,312 kg (77,687 lb)	43,420 kg (95,528 lb)	1,524 kg (3,352 lb)
	FINAL DISPOSAL					
	Sewage	43 kg (95 lb)	259 kg (570 lb)	273 kg (601 lb)	57[illegible] kg (1,266 lb)	
	Landfill	----------Unknown----------				
	NATURAL SOURCES					
	o Degassing				4,400 kg (9,590 lb)[c]	
	o Runoff				550 kg (1,210 lb)	
	o Groundwater				264 kg (580 lb)	

---

a. Emission by sector as a percent of total emissions to air (of water or land).
b. Percent of all emissions by sector to all emissions in the study region.
c. An estimated one-third (including mercury metal) is in soluble form; remainder moves rapidly into sediments.

Source: URS Research Company

Because the degassing rate assumed for the state was low, degassing from the earth's crust (which in this region includes a substantial amount of water bodies) contributed much less mercury to the environment than did man-related sources. Runoff contributions were also somewhat less than man-related discharges. (As discussed earlier, these runoff values do not include any mercury content of water "imported" into the region. Thus the Mississippi River, which has a mercury burden of its own accumulated through its passage through many states, does not show up as a major natural source within the study region. However, it is estimated that the total emissions to water for the study region are actually less than 5 percent of those carried through the study region by the Mississippi itself.)*

Industry in Louisiana deserves credit for undertaking the necessary control measures to reduce mercury discharges to meet the standards established by the EPA. Nevertheless, it must be noted that the state itself seems to have a laissez-faire attitude toward industrial waste dischargers. Perhaps the reliance of the state economy on the vast petrochemical and allied industries is responsible for this attitude. In any case, there is a considerable contrast in the matter of mercury emissions from industrial complexes in this region compared with those in other states where regulatory actions are even more strict than those mandated by the EPA.

New York/New Jersey Study Region

Table 13 gives the results of the analysis of the New York/New Jersey study region. The study area includes parts of New York, New Jersey, Pennsylvania, Delaware, and Connecticut and contains a varied range of mercury contributors.

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* It has been argued by some dischargers of mercury to the Mississippi River that for this reason alone it is foolish to be concerned about the discharge of low-level mercurial wastes to the Mississippi. We cannot condone this viewpoint, since widespread adoption of this attitude could only act to increase rather than to stabilize or decrease the mercurial burden presently carried by receiving waters.

TABLE 13. - Mercury Emissions to the Environment in the New York/New Jersey Study Region

Sector		Air	Water	Land	Total	Recycle
I	Mercury Mining and Smelting	-	-	-	-	-
II	Other Mining and Smelting	-	-	-	-	-
III	Unregulated Sources Livestock (0.00) Electric Utilities (0.37) Natural Gas (0.06) Tars and Asphalt (0.14) Refineries (0.02) Fuel Oil (0.27) Coal (0.13) Blast Furnaces (0.01)	10,473 kg (23,040 lb) (21%)[a]	161 kg (354 lb) (2%)[a]	2,071 kg (4,447 lb) (2%)[a]	12,655 kg (27,841 lb) (8%)[b]	-
V	Manufacturing and Processing Foam-Caustic (0.03) Catalysts (0.01) Other (0.28) Chlor-Alkali (0.58) Organic Chemicals (0.01) Inorganic Chemicals (0.00) Medicinal Chemicals (0.00) Tubes/Switches (0.05) Lamps (0.01) Batteries (0.01) Controls/Instruments (0.03)	3,489 kg (7,693 lb) (7%)	2,467 kg (5,439 lb) (24%)	16,608 kg (36,621 lb) (18%)	22,564 kg (49,753 lb) (15%)	1,745 kg (3,840 lb) (8%)
VIIIA	Final Consumption: Comm. and Industrial Lamps (0.17) Controls/Instruments (0.38) Tubes/Switches (0.21) Laboratory (0.04) Pesticides (0.17) Foam/Plastics (0.03)	3,306 kg (7,290 lb) (6%)	2,992 kg (6,598 lb) (28%)	26,394 kg (58,198 lb) (28%)	32,692 kg (72,086 lb) (21%)	16,339 kg (36,028 lb) (76%)
VIIIB	Final Consumption: Consumer Goods Pharmaceuticals (0.03) Paint (0.27) Batteries (0.67) Dental (0.03)	32,901 kg (72,547 lb) (66%)	4,844 kg (10,680 lb) (46%)	47,985 kg (105,806 lb) (52%)	85,730 kg (189,033 lb) (56%)	3,360 kg (7,391 lb) (16%)
	Totals	50,169 kg (110,570 lb)	10,464 kg (23,071 lb)	93,008 kg (205,072 lb)	153,641 kg (338,713 lb)	19,875 kg (47,259 lb)
	FINAL DISPOSAL					
	Sewage	107 kg (235 lb)	5,063 kg (11,164 lb)	2,491 kg (5,494 lb)	7,661 kg (16,893 lb)	
	Landfill	-----------Unknown-----------				
	NATURAL SOURCES					
	o Degassing				4,800 kg (10,550 lb)	
	o Runoff				170 kg[c] (375 lb)	
	o Groundwater				137 kg (301 lb)	

---

a. Emission by sector as percent of total emissions to air (or land or water).
b. Percent of all emissions by sector to all emissions in study region.
c. An estimated one-third (including mercury metal) in soluble form; remainder moves rapidly into sediments.

Source: URS Research Company

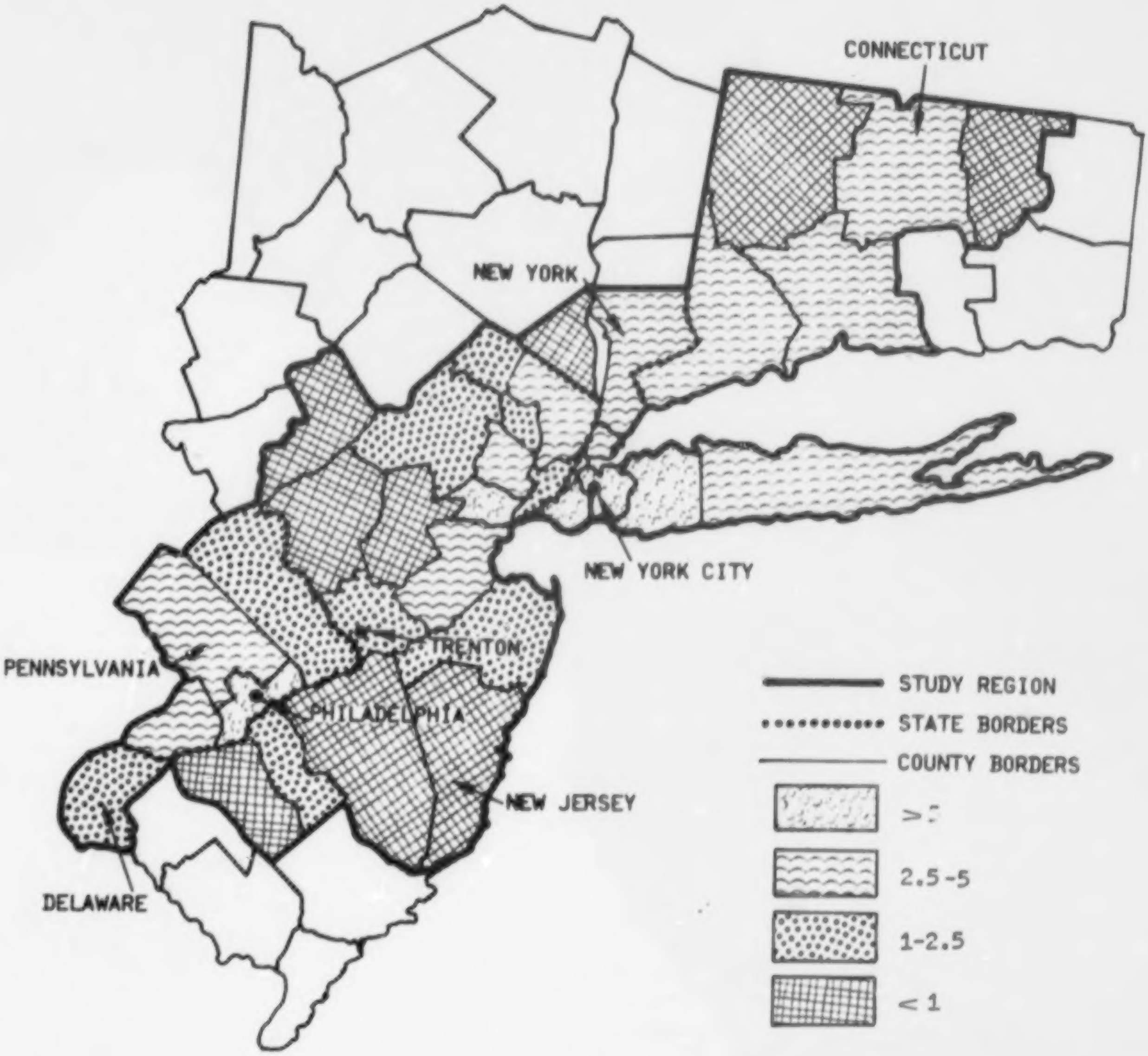
Chemical manufacturing facilities, which are highly concentrated in northeastern New Jersey, contribute relatively small amounts of mercury, principally because their water discharges are closely monitored by regulatory agencies. Electrical equipment manufacturing, although it too is concentrated here, also contributes relatively small amounts of mercury to the environment.

Mercury emissions to air from other sources are more significant. New York City and communities in its vicinity incinerate up to 40 percent of their solid wastes. Via incineration, mercury-containing batteries, lamps, control instruments, tubes, and switches contribute significant amounts of mercury to the atmosphere. For example, in a test conducted of New York's 73rd Street incinerator, mercury concentrations ranged from 4.8 to 9 ppm (Ref. 106). With 635 metric tons of solid waste incinerated daily at the facility, this amounts to approximately 3.0 to 5.7 kg of mercury per day, or 1,100 to 2,100 kg of mercury per year released to the air from this incinerator alone. (This assumes that all the mercury becomes volatilized, which of course is not the case, but the figures do provide a range that probably encompasses the true value.) For all seven New York City incinerators, the mercury emitted to the air could range from 10,000 to 19,000 kg per year. Our inventory of the city and adjacent areas indicated that just over 17,000 kg of mercury are emitted to the air from all sources. Assuming our inventory is reasonably accurate, incineration is obviously one of the prime contributors of emissions to air.

In contrast to the other study regions, in the New York/New Jersey region natural sources contributed substantially less than did man-related sources. This is attributable to the very high population density of this relatively small area. The implications of population density, and of population-at-risk with respect to exposure to mercury in one form or another, will be discussed later.

As for the Kentucky/Tennessee study region, the New York/New Jersey region was also analyzed on a county-by-county basis, in order to pinpoint zones of relatively high or low mercury losses. This analysis was completed for all three environmental parameters, even though water losses, because of rigorous controls, are quite low.

Figure 13 shows that the greatest loss of mercury to the air occurs in the Philadelphia and New York metropolitan areas. One of the primary sources is


CONNECTICUT
NEW YORK
NEW YORK CITY
PENNSYLVANIA
TRENTON
PHILADELPHIA
NEW JERSEY
DELAWARE
STUDY REGION
STATE BORDERS
COUNTY BORDERS
>5
2.5-5
1-2.5
< 1

SOURCE: URS Research Company.

Figure 13 MERCURY EMISSIONS TO AIR IN NEW YORK/NEW JERSEY STUDY REGION, BY COUNTY, 1973
(thousands of pounds)

consumer paint usage. Other major contributors are fossil fuels and incineration. Figure 14 shows that emissions to water are also highest in the New York and Philadelphia metropolitan areas and in northeastern New Jersey. Mercury emissions to water are well controlled by law, and our analysis indicates that dental and pharmaceutical uses, "other," and vat dye manufacture contribute the greatest quantities to this medium.

Figure 15 shows that land emissions follow the same general pattern. The principal losses arise from the disposal of electrical apparatus and chlor-alkali plant sludges.

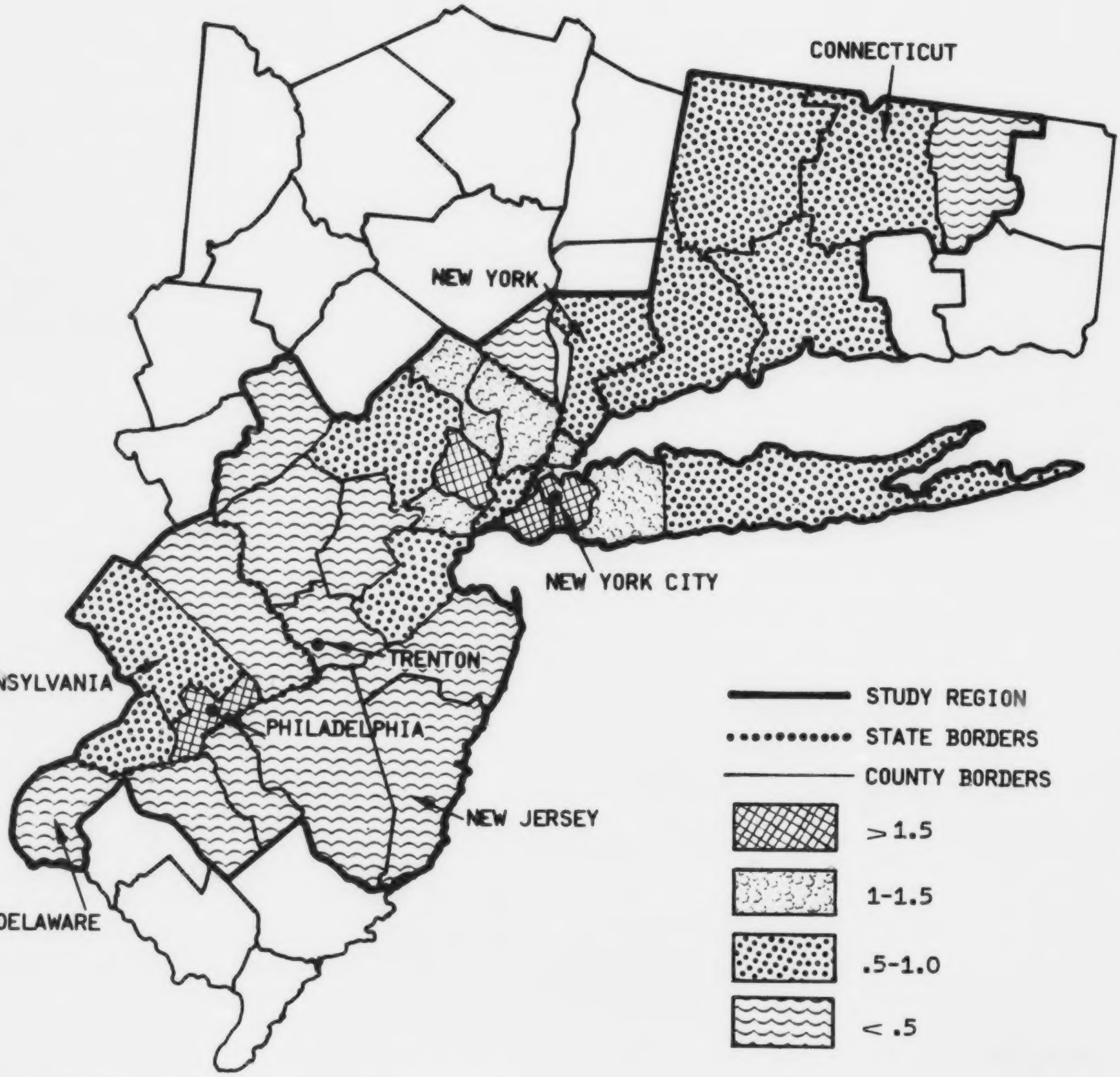
A latitude/longitude analysis was undertaken to compare various sections within the area to identify "hot spots" of emissions. Figure 16 shows the areas chosen for analysis and Table 14 presents the results, showing mercury losses per 1,000 population. The most striking feature of the table is the large per capita loss to land in eastern New Jersey (Box C). Primary contributors in the point source category are a chlor-alkali plant, sludges from chemical plants, and users of nonfarm pesticides.

The upper and lower portions of the Long Island Sound estuary (Boxes D and E) were compared. The upper estuary contributes much more mercury, on a per capita basis, then does the lower. Since the upper estuary (primarily Connecticut) is much more industrialized than the lower (Long Island), this result is not surprising.

National Inventory

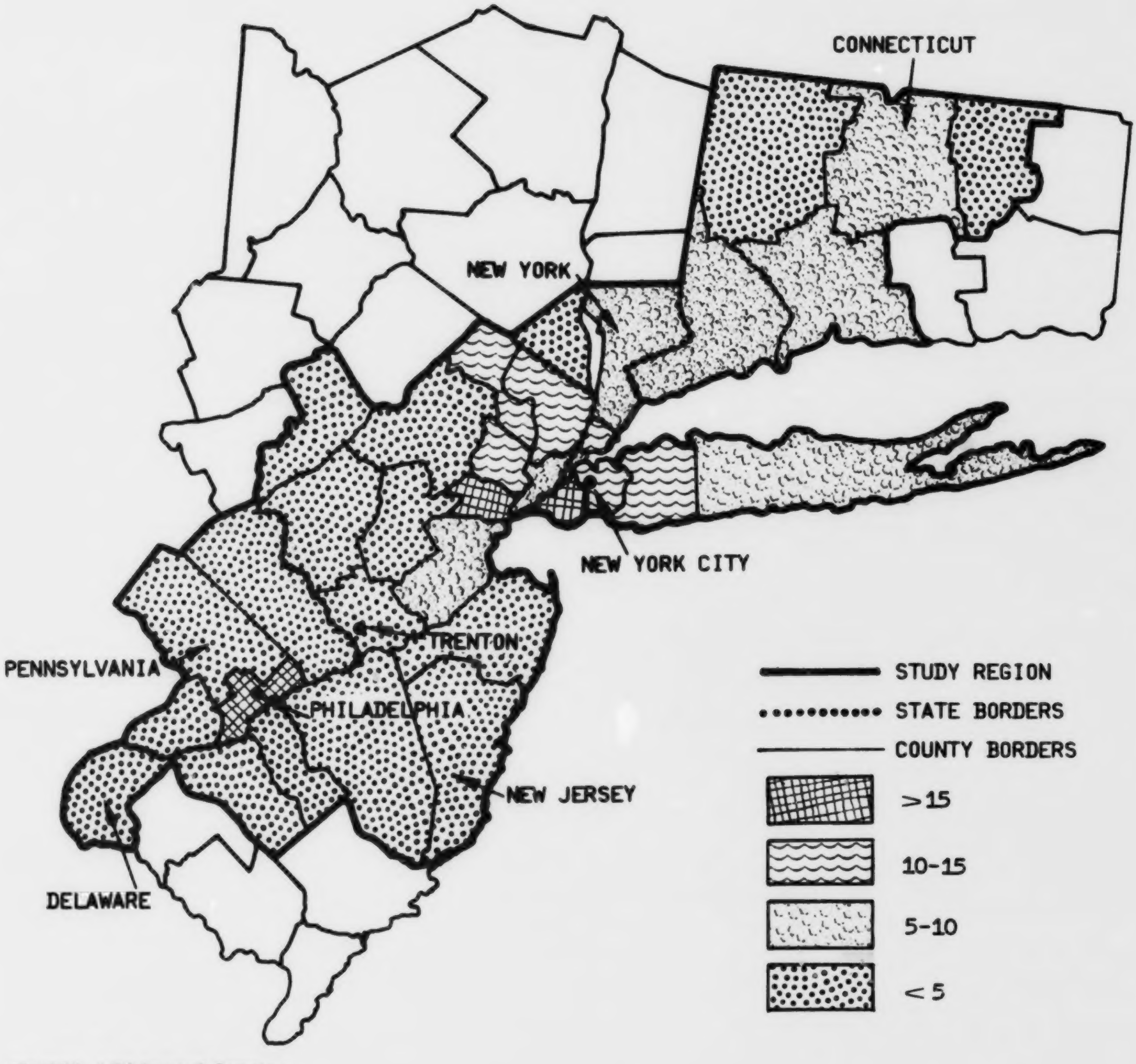
Mercury emissions in the coterminous United States were determined in a manner similar to that employed for each study region. However, these estimates were reached independently and are not a summation of results for the study regions. The results for the national inventory are found in Table 15, which shows mercury losses by sector and SIC category, and in Table 16, which shows losses by state, with total losses to land, water, air, and recycling (with contributions from sewage, urban runoff, and natural sources).

A study of Table 15 indicates that in 1973 the total man-related losses in the United States were an estimated 1,525,100 kg. Of this total 31 percent was directed to air, 6 percent to water, and 63 percent to land. An additional


CONNECTICUT
NEW YORK
NEW YORK CITY
TRENTON
PENNSYLVANIA
PHILADELPHIA
NEW JERSEY
DELAWARE
STUDY REGION
STATE BORDERS
COUNTY BORDERS
>1.5
1-1.5
.5-1.0
< .5

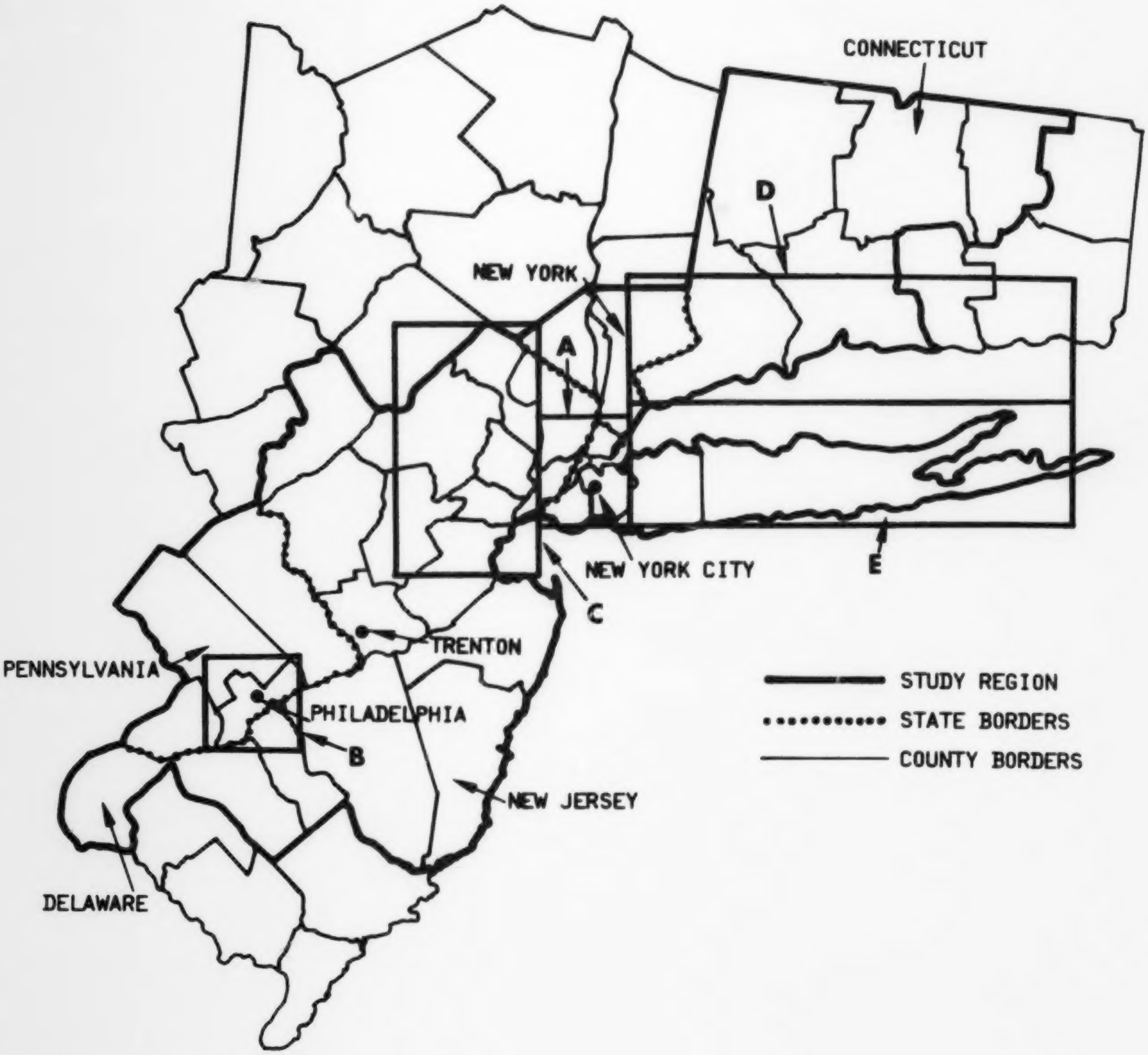
SOURCE: URS Research Company.

Figure 14 MERCURY EMISSIONS TO WATER IN NEW YORK/NEW JERSEY STUDY REGION, BY COUNTY, 1973 (thousands of pounds)


CONNECTICUT
NEW YORK
NEW YORK CITY
TRENTON
PENNSYLVANIA
PHILADELPHIA
NEW JERSEY
DELAWARE
STUDY REGION
STATE BORDERS
COUNTY BORDERS
>15
10-15
5-10
<5

SOURCE: URS Research Company.

Figure 15 MERCURY EMISSIONS TO LAND IN NEW YORK/NEW JERSEY STUDY REGION, BY COUNTY, 1973
(thousands of pounds)


CONNECTICUT
D
NEW YORK
A
NEW YORK CITY
E
C
TRENTON
PENNSYLVANIA
PHILADELPHIA
B
NEW JERSEY
DELAWARE
STUDY REGION
STATE BORDERS
COUNTY BORDERS

SOURCE: URS Research Company.

Figure 16 LATITUDE/LONGITUDE ANALYSIS AREAS IN NEW YORK/NEW JERSEY STUDY REGION

TABLE 14. - Per Capita Distribution of Mercury losses to Air, Land, and Water in Five Areas of New York/New Jersey Study Region[a]
(kilograms per 1,000 population)

	A New York City	B Philadelphia	C Eastern New Jersey	D Upper Estuary	E Lower Estuary
Losses from Point Sources[b] to					
Air	0.4	1.0	1.1	0.6	0.4
Land	0.4	0.4	5.4	0.9	0.1
Water	0.1	0.1	0.5	0.1	0.1
Totals	0.9	1.5	7.0	1.6	0.6
Losses from All Sources[c] to					
Air	2.1	2.0	2.4	2.1	1.1
Land	2.8	3.9	9.8	3.8	1.5
Water	0.4	0.4	0.9	0.5	0.2
Totals	5.3	6.3	13.1	6.4	2.8

a. See Figure 17 for area delineation.

b. Includes losses from Sectors I, II, III, and V.

c. Includes losses from all sectors.

Source: URS Research Company.

TABLE 15. - Total Mercury Losses in 1973 for the Coterminous United States, By Sector and SIC Category[a] (thousands of kilograms)

Sector	SIC No.	Description	Total Losses to			Total Mercury Lost	Total Recycled
			Air	Water	Land		
I		Mercury Mining & Smelting					
	1092M	Mercury Mining	0.01	0.00	0.01	0.02	0.00
	1092P	Mercury Processing (including secondary)	7.84	0.00	0.41	8.25	0.00
		Subtotals	7.85 (1.7%)	0.00 (0.0%)	0.42 (0.0%)	8.27 (0.5%)	0.00 (0.0%)
II		Other Mining					
	1021	Copper Mining	0.02	0.01	0.08	0.11	0.00
	1031	Zinc and Lead Mining	0.00	0.00	0.01	0.01	0.00
	3331	Copper Smelting	40.77	2.26	2.26	45.29	0.00
	3333	Zinc Smelting	4.59	0.25	0.25	5.09	0.00
	3241	Cement Processing	0.50	0.25	1.76	2.51	0.00
	3274	Lime Processing	0.08	0.04	0.29	0.41	0.00
	3332	Lead Smelting	4.75	0.26	0.26	5.27	0.00
		Subtotals	50.71 (10.8%)	3.07 (3.5%)	4.91 (0.5%)	58.09 (3.8%)	0.00 (0.0%)
III		Unregulated Sources					
	021	Livestock	0.00	0.0	17.70	17.70	0.00
	2911C	Fuel Oil - Residential, Commercial, Industrial	16.94	0.00	0.02	16.96	0.00
	2911M	Refineries	1.15	0.00	1.15	2.30	0.00
	2951C	Tars and Asphalt	1.10	1.67	14.99	17.76	0.00
	3312M	Coke Ovens	7.16	0.51	2.56	10.23	0.00
	4091C	Coal - Residential, Commercial, Industrial	9.97	0.00	1.11	11.08	0.00
	4911O	Utilities - Oil and Natural Gas	11.99	0.00	0.01	12.00	0.00
	4924C	Natural Gas - Residential, Commercial, Industrial	15.46	0.00	0.01	15.47	0.00
	4911C	Utilities - Coal	40.71	0.00	4.52	45.23	0.00
		Subtotals	104.48 (22.2%)	2.18 (2.5%)	42.07 (4.4%)	148.73 (9.8%)	0.00 (0.00%)
V		Manufacturing & Processing					
	2.5B	Caustic	0.00	7.61	1.90	9.51	0.00
	2819M	Catalyst Manufacture	0.00	0.02	0.00	0.02	0.00
	2851M	Paint Manufacture	0.01	0.20	0.05	0.26	0.00
	2879M	Pesticide Manufacture	0.00	0.06	0.00	0.06	0.00
	2833M	Pharmaceuticals Manufacture	0.00	0.02	0.00	0.02	0.00
	2812	Chlor-Alkali	14.84	2.93	226.83	244.60	0.00
	2261	Textiles	0.00	0.15	7.63	7.78	0.00
	2851F	Paint Formulation	0.29	0.35	0.00	0.64	0.00
	38291M	Control Instrument Manufacture	0.00	0.00	1.97	1.97	1.97
	3079P	Catalyst Usage	0.05	0.10	18.85	19.00	0.00
	3.0	Other	10.28	10.23	8.70	29.21	20.66
	36292M	Tubes/Switches Manufacture	0.00	0.00	1.57	1.57	0.00
	36410M	Lamp Manufacture	0.40	0.00	1.34	1.74	0.00
	36420M	Battery Manufacture	0.13	0.05	2.49	2.67	0.00
		Subtotals	26.00 (5.5%)	21.72 (24.8%)	271.33 (28.1%)	319.05 (21.0%)	20.66 (14.1%)
VIIIA		Final Consumption: Comm. & Industrial					
	2.5A	Urethane & Misc.	0.12	0.00	2.22	2.34	0.00
	2879N	Nonagricultural Pesticide Use	4.39	17.56	21.95	43.90	0.00
	2879A	Agricultural Pesticide Use	0.00	2.83	16.02	18.85	0.00
	38291C	Control Instrument Consumption	16.54	0.00	107.50	124.04	82.69
	36292C	Tubes/Switches Consumption	7.53	0.00	46.26	53.79	0.00
	26410C	Lamp Consumption	6.07	0.00	37.31	43.38	0.00
	7391	Laboratory Usage	2.28	5.92	1.59	9.79	12.98
		Subtotals	36.93 (7.8%)	26.31 (30.0%)	232.85 (24.1%)	296.09 (19.4%)	95.67 (65.2%)

TABLE 15. - Total Mercury Losses in 1973 for the Coterminous United States, By Sector and SIC category)[a] (thousands of kilograms) (continued)

Sector	SIC No.	Description	Total Losses to			Total Mercury Lost	Total Recycled
			Air	Water	Land		
VIIIB		Final Consumption: Consumer Goods:					
	2834C	Pharmaceuticals Consumption	1.04	17.77	2.09	20.90	0.00
	2851C	Paint Consumption	173.61	0.00	9.14	182.75	0.00
	36420C	Battery Consumption	69.71	0.00	403.30	473.01	24.89
	8021	Dental Applications	0.93	16.65	0.00	17.58	5.55
		Subtotals	245.29 (52.0%)	34.42 (39.2%)	414.53 (42.9%)	694.24 (45.5%)	30.44 (20.7%)
Total			471.26	87.70	966.11	1,525.07	146.77
Final Disposal							
Sewage			4.01	19.92	22.88	46.80	-
Urban Runoff			0.00	11.70	0.00	11.70	
Natural Sources							
o Degassing			1,018.70	0.00	0.00	1,018.70	-
o Runoff and Groundwater			0.00	188.30	0.00	188.30	-

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[a] The values of losses in some cases vary slightly from those given in Section IV (Technology Assessment) because of refinements in the data base that are reflected in the latter section. However, such differences as do occur are small and do not affect the findings of the report; hence no attempt has been made to adjust the values in this table.

Source: URS Research Company.

TABLE 16. - Total Mercury Losses in 1973 for the Coterminous United States, by State
(thousands of kilograms)

State	Losses from Man-Made Sources to				Losses from Natural Sources to		Losses from Sewage	Losses from Urban Runoff
	Land	Water	Air	Recycling	Degassing	Runoff		
Alabama	41.02	1.56	9.89	2.46	9.59	4.14	0.59	0.39
Arizona	6.88	1.76	22.28	0.96	85.77	11.33	0.46	0.19
Arkansas	7.09	0.72	3.04	1.32	9.82	1.97	0.89	0.15
California	65.22	7.57	36.75	13.10	118.25	26.30	5.20	1.40
Colorado	7.76	0.94	3.51	1.17	39.24	6.01	0.51	0.20
Connecticut	11.72	1.29	6.05	2.85	1.84	0.01	0.58	0.15
Delaware	10.58	0.35	1.93	0.44	0.37	0.01	0.13	0.05
Florida	20.59	2.41	12.07	3.35	10.25	0.77	1.53	0.71
Georgia	28.17	1.92	9.53	3.46	21.96	2.73	0.96	0.35
Idaho	2.63	0.40	2.78	0.48	31.27	6.30	0.15	0.08
Illinois	47.60	4.56	22.44	9.21	10.54	1.41	2.78	0.64
Indiana	21.12	2.27	12.17	4.79	6.82	3.22	1.12	0.36
Iowa	10.87	1.04	5.65	1.77	10.58	5.88	0.64	0.28
Kansas	11.02	1.41	3.66	1.25	15.46	5.68	0.52	0.15
Kentucky	29.45	1.35	10.51	2.12	7.50	2.18	0.65	0.11
Louisiana	46.15	1.53	8.38	1.76	8.49	1.18	0.82	0.27
Maine	7.36	0.45	2.54	0.82	5.85	0.49	0.19	0.10
Maryland	13.25	1.57	7.56	2.64	3.74	0.30	0.96	0.40
Massachusetts	20.93	2.32	11.37	4.71	2.96	0.14	1.32	0.26
Michigan	33.03	3.72	18.83	7.77	10.74	0.63	2.01	0.45

TABLE 16. - Mercury Losses for 1973 for the Coterminous United States, by State
(thousand of kilograms)
(continued)

State	Losses from Man-Made Sources to				Losses from Natural Sources to		Losses from Sewage	Losses from Urban Runoff
	Land	Water	Air	Recycling	Degassing	Runoff		
Minnesota	13.94	1.51	7.02	2.51	14.94	0.81	0.89	0.26
Mississippi	7.59	0.82	5.11	1.41	8.94	5.97	0.42	0.13
Missouri	17.24	2.02	13.78	3.29	13.04	4.28	0.95	0.38
Montana	4.17	0.74	3.97	0.28	55.01	4.56	0.15	0.07
Nebraska	6.15	0.71	2.31	0.78	14.46	1.87	0.36	0.10
Nevada	1.89	0.32	5.64	0.20	83.10	4.18	0.13	0.07
New Hampshire	2.94	0.32	1.44	0.67	3.42	0.10	0.15	0.05
New Jersey	41.90	3.37	14.57	6.18	1.42	0.17	1.80	0.18
New Mexico	2.98	0.51	4.87	0.37	45.91	20.66	0.24	0.10
New York	78.44	7.14	35.47	13.03	18.10	0.61	4.38	0.59
North Carolina	25.28	2.17	12.23	4.65	18.46	1.25	0.94	0.33
North Dakota	6.39	0.97	0.91	0.19	13.10	0.91	0.14	0.05
Ohio	43.48	4.49	25.33	9.51	7.75	1.80	2.49	0.57
Oklahoma	10.50	1.27	4.57	1.38	13.00	25.47	0.61	0.65
Oregon	7.13	0.81	3.61	1.33	72.74	2.60	0.45	0.13
Pennsylvania	46.22	5.12	34.83	10.27	17.00	0.83	2.72	0.43
Rhode Island	3.94	0.41	1.82	0.90	0.20	0.02	0.21	0.03
South Carolina	12.98	1.15	5.49	2.27	5.71	1.14	0.49	0.45
South Dakota	3.44	0.42	1.11	0.27	14.36	1.27	0.15	0.09
Tennessee	31.67	2.27	10.00	3.18	7.81	5.24	1.05	0.39
Texas	59.43	4.70	25.89	6.68	49.56	18.53	2.78	1.43
Utah	3.62	0.72	7.84	0.57	31.03	2.98	0.28	0.12
Vermont	1.45	0.15	0.69	0.29	2.19	0.15	0.09	0.02
Virginia	15.33	1.76	8.14	3.05	15.04	1.07	0.99	0.39
Washington	22.43	1.50	8.98	2.13	25.18	0.87	0.74	0.14

TABLE 16. - Total Mercury Losses in 1973 for the Coterminous United States, by State
(thousands of kilograms)
(continued)

State	Losses from Man-Made Sources to				Losses from Natural Sources to		Losses from Sewage	Losses from Urban Runoff
	Land	Water	Air	Recyling	Degassing	Runoff		
West Virginia	31.22	0.80	5.36	1.01	9.10	0.58	0.34	0.11
Wisconsin	20.71	2.31	8.39	3.68	10.30	0.92	1.02	0.11
Wyoming	1.18	0.11	0.74	0.13	36.76	2.90	0.08	0.04
Totals	966.08	87.73	471.05	146.60	1,018.67	192.42	46.55	13.37

Source: URS Research Company

146,800 kg were recycled. Sector VIIIB (personal consumption) accounted for 45.5 percent of the total, followed by 21 percent for manufacturing (Sector V) and 19 percent for industrial and commercial consumption (Sector VIIIA). Total losses through sewage were estimated to be 46,800 kg, as compared with a total of 87,700 kg from all man-related emissions to water--a reasonable comparison. The estimated emissions from natural sources were slightly more than 1 million kg (as compared to 471,000 kg to air from man-related sources) from surface runoff and 188,000 kg from underground waters (as compared with 87,700 kg from man-related losses to water). Finally, on a national basis, an estimated 12,000 kg of mercury are lost as a result of urban runoff.

In Table 17 the results for the national inventory are compared with those of the various regions. In Part A of the table the comparison is by sector and indicates the differences found in the regions studied. As discussed earlier, there were significant variations attributable to specific sources in each region. This suggests that the choice of regions for study was very valuable in terms of highlighting different use and discharge patterns.

In Part B of the table, total man-related losses (by environmental receptor) are compared on a national and a regional basis. Again significant differences between regions can be noted. However, if the major perturbations in a given region are recognized and discounted (for example copper smelters in the Arizona region), the results for the regions approach the national norm.

In Part C of the table, total man-related losses versus total mercury losses from natural sources are listed for both the national and regional results. As anticipated, the ratios between man-related and natural (degassing) emissions to air vary widely, as do those for man-related emissions to water versus those for runoff plus groundwater. On a regional basis these ratios are strongly affected by the amounts of man-related emissions (amounts that are primarily related to population density and to manufacturing activities that utilize mercury) and by the relative size of the region. The New York/New Jersey study region, with the highest population density and the smallest total land area of the selected study regions, is greatly above the national average with respect to both ratios.

TABLE 17. - Comparison of Regional and National Inventory Results

A. Total Man-Related Losses, by Sector

		Percent of Total Losses					
Sector	Name	National	California	Arizona	Kentucky/ Tennessee	Louisiana	New York/ New Jersey
I	Mercury Mining	0.5%	11.5%	0%	0%	0%	0%
II	Other Mining	4.0	0.5	64.0	1.0	0	0
III	Unregulated	10.0	5.0	4.0	44.5	5.0	21.0
V	Manufacturing	21.0	5.0	2.0	12.0	71.0	7.0
VIIIA	Consumption-Ind.	19.0	20.0	6.0	0.5	5.0	6.0
VIIIB	Consumption-Pers.	45.5	58.0	24.0	42.0	19.0	66.0
	Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

B. Total Man-Related Losses, by Environmental Receptor

	Percent of Total Losses					
Losses to	National	California	Arizona	Kentucky/ Tennessee	Louisiana	New York/ New Jersey
Air	31.0%	31.0%	68.0%	29.0%	16.5%	33.0%
Water	6.0	8.0	6.0	4.5	2.5	7.0
Land	63.0	61.0	26.0	66.5	81.0	60.0
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

C. Ratio of Total Man-Related Losses to Losses from Natural Resources

Ratio	National	California	Arizona	Kentucky/ Tennessee	Louisiana	New York/ New Jersey
Man-Related (air) Degassing	0.46%	0.41%	0.28%	1.37%	1.69%	10.47%
Man-Related (water) Runoff	0.47	0.49	0.34	0.42	1.17	34.08

Source: URS Research Company

Because population density is an important consideration, the emission data in Table 16 were normalized on the basis of population. The mean and standard deviations, in terms of kilograms of mercury emitted per 1,000 population, were as follows: air, 1.81 ± 0.53; water, 0.41 ± .08; land, 4.55 ± 1.20. The results for each state were then plotted on maps that showed the average case as ± 1 standard deviation, variations as greater than 15.0, and hot spots as greater than 25.0. These results are shown in Figures 17 through 19. In all cases, it was possible to identify hot spots as being related to either chlor-alkali plants or copper smelting facilities. However, the presence of such activities in a given state did not necessarily result in overall elevated concentrations for the region.

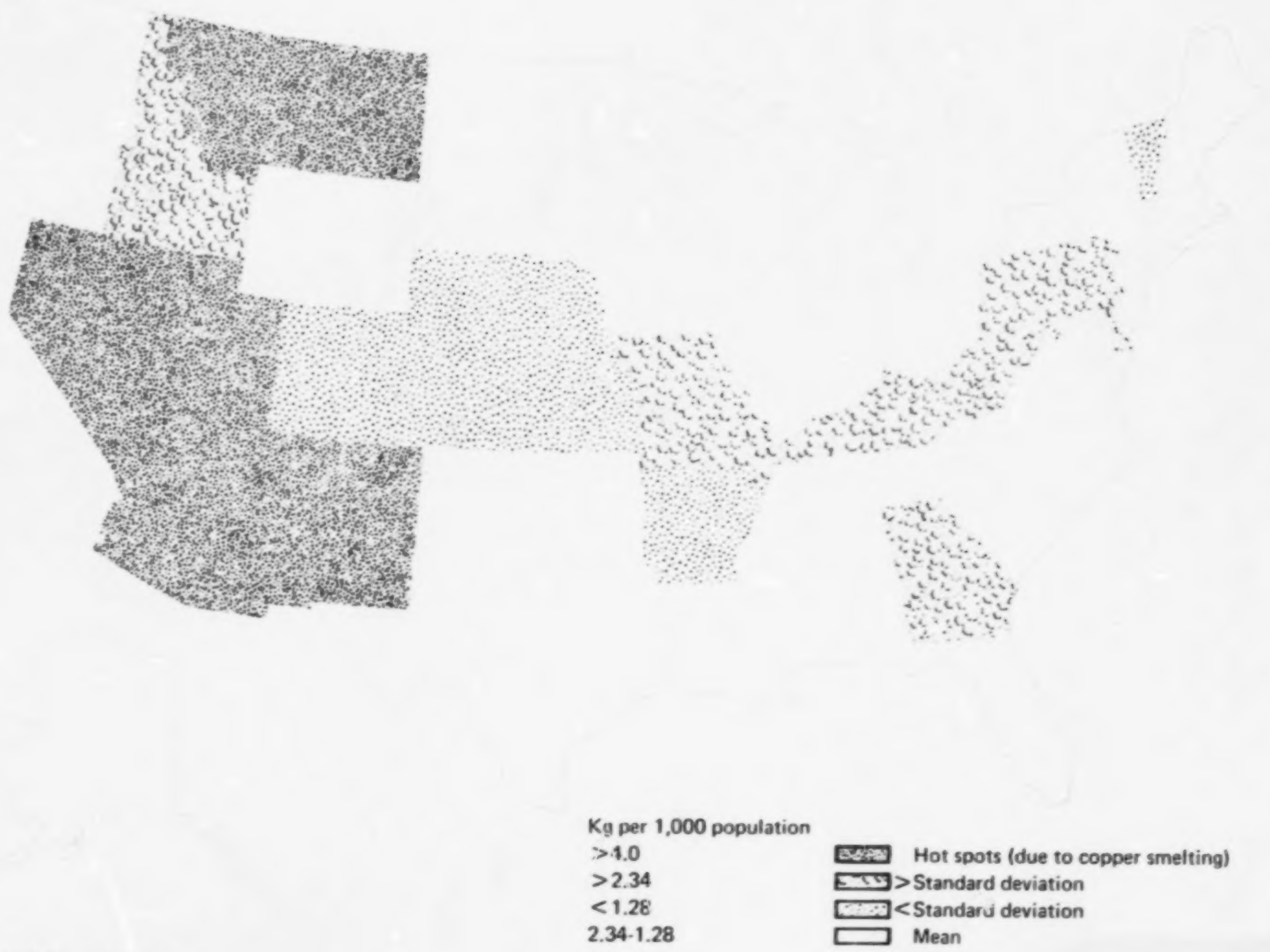
Risk Analysis

In general our findings indicated that final consumption (Sectors VIIIA and VIIIB) represented relatively constant emissions on a per capita basis both nationally and for each study region. Indeed, the more highly populated study regions have proportionately higher total mercury losses. But at the same time we recognized that total mercury emissions might also be related to land area. To test this possible relationship we plotted, for various study regions and for selected states, emissions to land, air, and water (in terms of kilograms of mercury per square kilometer) as a function of population density (in terms of thousands of persons per square kilometer). Initially the correlation was not obvious, but when we discounted the hot spots identified in Figures 17 through 19, we obtained the surprisingly good correlations shown in Figure 20. Emissions per square kilometer increase proportionately to the population, but the rate of increase is markedly different for land, air, and water emissions.

The relationships shown in Figure 20 can be reduced to a simple equation:

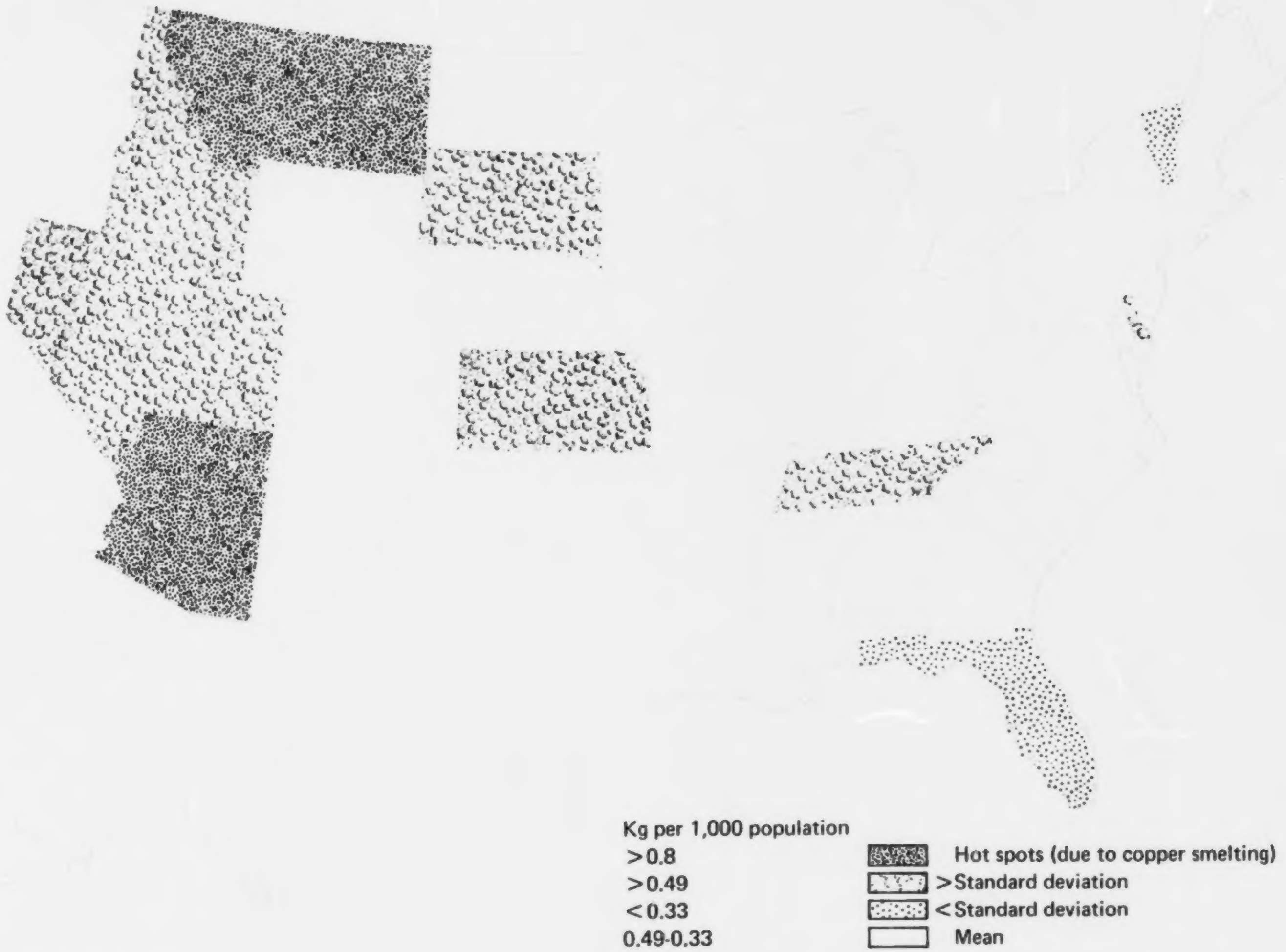
$$\text{Emissions (in kg)/km}^2 = K\ (\text{population/km}^2)$$

where the value of K is:


Kg per 1,000 population
>4.0 Hot spots (due to copper smelting)
>2.34 >Standard deviation
<1.28 <Standard deviation
2.34-1.28 Mean

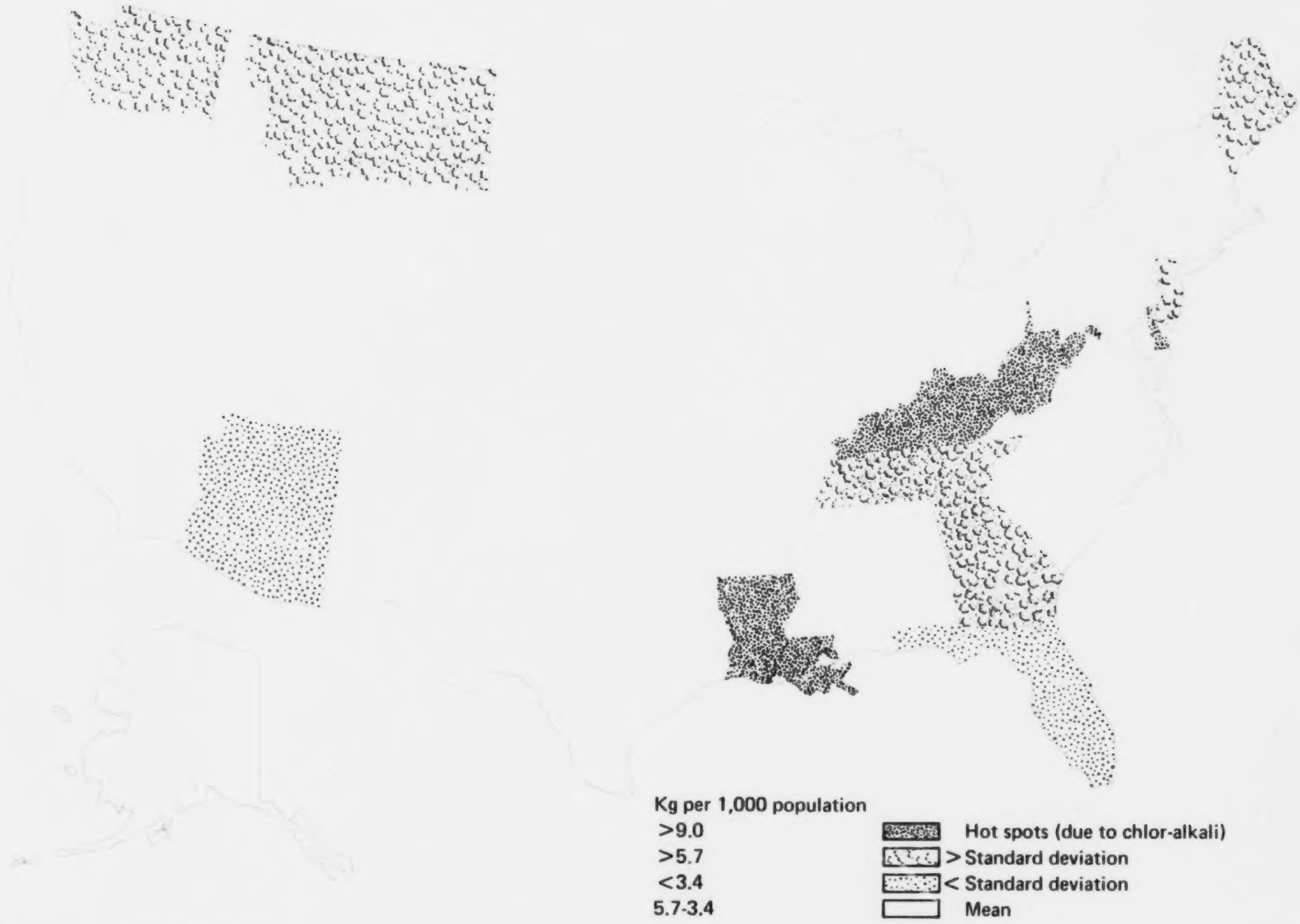
SOURCE: URS Research Company.

Figure 17 ANNUAL ELEVATED MERCURY LOSSES TO AIR


Kg per 1,000 population
>0.8 ▩ Hot spots (due to copper smelting)
>0.49 ▨ >Standard deviation
<0.33 ▒ <Standard deviation
0.49-0.33 ☐ Mean

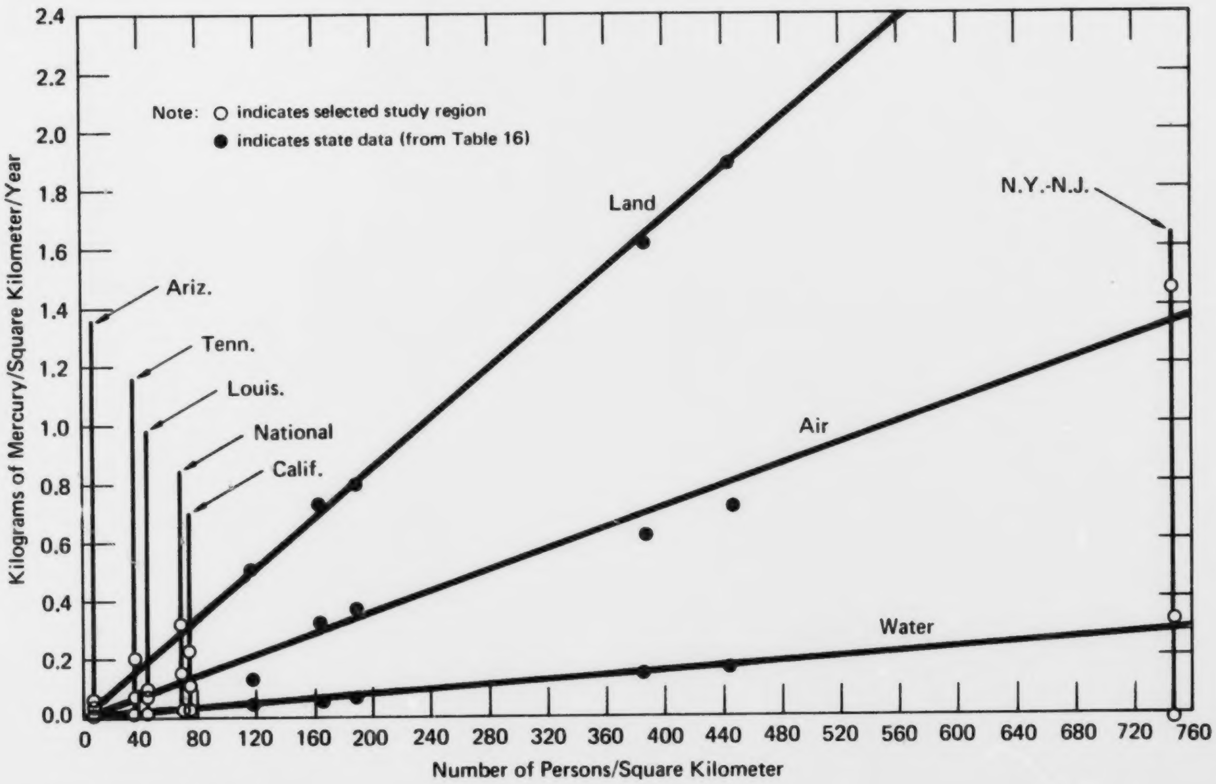
SOURCE: URS Research Company.

Figure 18 ANNUAL ELEVATED MERCURY LOSSES TO WATER


Kg per 1,000 population
>9.0
>5.7
<3.4
5.7-3.4
▨ Hot spots (due to chlor-alkali)
▨ > Standard deviation
▨ < Standard deviation
☐ Mean

SOURCE: URS Research Company.

Figure 19 ANNUAL ELEVATED MERCURY LOSSES TO LAND



SOURCE: URS Research Company.

Figure 20 MERCURY EMISSIONS AS A FUNCTION OF POPULATION DENSITY

Air = 0.00180
Water = 0.000385
Land = 0.00425

This equation can be further simplified by eliminating areal considerations, so that we obtain the following per capita emission factors:

Receiving Medium	Per Capita Emission Factor (grams/person)
Air	1.80
Water	0.385
Land	4.25

These factors make it possible to estimate quickly the expected emissions from any population base.*

From this simple model it is possible to show the impact on a community of new activities that emit mercury and to assess the importance of emissions from natural sources on a given population--notably the population at risk. To illustrate, consider two cities with the following characteristics:

	City A	City B
Area (km^2)	100	200
Population	50,000	500,000
Density (pop./km^2)	500	2,500
Per capita air emissions (kg/person)	0.00180	0.00180
Total annual mercury contribution to air (kg)	90	900

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* The usefulness of the regional and national inventories is again demonstrated by these per capita emission factors. Based on national values only, the per capita emission factors were found to be 1.40g/person for air, 0.304 for water, and 3.24 for land. The values derived from Figure 20 then more nearly represent the average case (which includes the effects of metropolitan areas) and can safely be used to estimate per capita emission factors for the higher population densities found in metropolitan areas.

Now consider the addition of a new industrial activity designed to release to the air no more than 0.1 kg of mercury per day (36.5 kg per year). For City A this added burden represents an increase of over 40 percent, but for City B the added burden is only 4 percent. In other words, the added burden has a much more noticeable effect on the quality of the air in the smaller community. But contributions from natural sources must also be considered. Using the national average degassing rate of $0.337\ \mathrm{kg/km}^2$ per year, City A will add another 33.7 kg from this source to its man-related base contribution of 90 kg per year--or an additional 37 percent. For City B the additional burden from natural degassing within its own boundaries will equal 67.4 kg per year, an increase of only 7.5 percent over man-related contributions.*

In terms of a population exposed to an additional mercury burden, it would appear that City B (high population density) would be least affected. However, if mercury vapor concentrations are already high, a small incremental increase would merely perpetuate an already bad situation, at the same time exposing a large group of people. On the other hand, if a mercury-emitting activity is established in an area of lower population density, this new source adds significantly to the assumed low concentrations which are already present. Therefore the impact is small in terms of people exposed and resultant concentrations, although the relative increase in mercury burden is unquestionably high. The problem then, in evaluating new or existing emitters, is to limit emissions to the environment to the greatest extent possible, so that the resultant impacts are as negligible as possible.

This case study illustrates the fact that the population itself could be the major source of the mercury pollution it experiences (obviously point source and industrial discharges, if not well controlled, could be much greater--at least locally--than population-derived emissions). The case study also suggests that natural sources and background can be important factors in the total picture. On a regional basis natural sources also have some interesting implications. Figure 20 shows that the average annual degassing rate for the nation is 0.34 kg/km^2, which can be equated with the contribution from a population density of 190 persons per square kilometer--that of the State of Ohio, say. The average annual contribution from runoff from surface waters plus groundwaters accounts, on the national basis, for 0.062 kg/km^2, equivalent to the contribution from a population density of 150 persons per square kilometers.* Thus, even in smaller but heavily populated states, natural sources are important.

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* We recognize that metropolitan areas will almost certainly degas at different rates from those for the general countryside, and that "incoming" air carries a global mercury burden. However, we use degassing within the corporate boundaries for illustrative purposes and to indicate the importance of various sources of mercury to the inhabitants.

SELECTION OF TECHNOLOGIES FOR STUDY

One of the reasons for developing regional and national inventories is to identify emitters that, on either a local or a national basis, generate sufficient waste products that are emitted to the environment to be of special concern. For mercury, these emissions are summarized, for the national basis, in Figure 21. From the figure certain obvious emitters can be identified; these require further consideration as far as technologic and economic evaluation is concerned (for example, chlor-alkali in the manufacturing sector and battery consumption in the final consumption sector). A brief discussion of the information shown in Figure 21 and detailed in Table 15 follows.

In Sector I, mercury mining and processing contribute only 0.5 percent of the total mercury lost in the nation annually, although for the State of California this value rises to 11.5 percent. Because mercury production is an essential link in this study and because its production in the United States may well increase significantly in future years as market demand grows, it was selected

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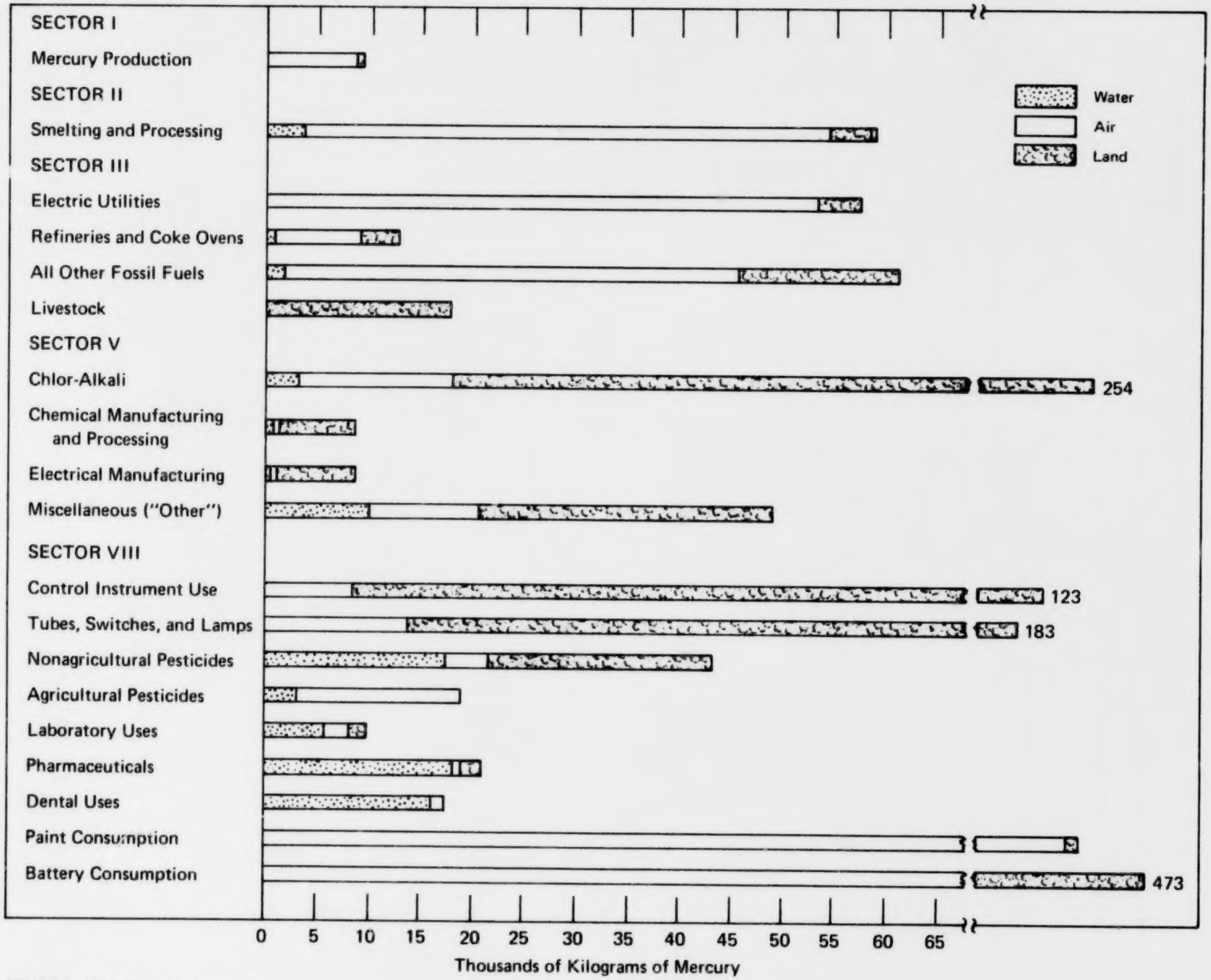
* We hesitate to place much importance on applying a contribution factor from natural waters to even regional comparisons because of the variations in stream flow, geology, etc. of different regions. However, the value for the national average, encompassing all types of situations, is believed valid and can be used cautiously for purposes of making comparisons.



SOURCE: URS Research Company.

Figure 21 SUMMARY OF MERCURY LOSSES TO THE U.S. ENVIRONMENT BY SECTOR AND CLASS, 1973

for study. However, the secondary mercury processing industry--that is, the recovery of mercury from its final use--is not considered. This industry was well covered in a previous study (Ref. 38). Also, contacts with representatives of the industry indicated that no substantial changes have occurred in recent years. Certainly the industry is well aware of the hazards of mercury, and total (estimated) emissions are very small.

In Sector II, copper smelting accounts for more than 75 percent of all emissions. For this reason, copper mining and smelting were selected for further study. However, it was not considered necessary to study zinc and lead mining and smelting, since the mercury content of these ores is similar to that for copper and the technology is not very different with respect to the ways in which mercury is released to the environment. (It might be noted that some recovery of mercury from zinc smelters is currently under way in the country.) Cement and lime processing were considered initially as a possible source of mercury release to the atmosphere, but it was soon found that the total quantities involved are low and that the impact, even on a regional basis, is insignificant. Phosphate rock, which may be heated in the kiln or applied directly to land as a fertilizer, was also considered as a possible source of serious losses to the environment. While it is true that phosphate rock does have a background mercury content, even with the high volume of usage the total quantities of mercury involved do not present any problem with respect to processing or concentration in soils. A more serious problem, discussed under Final Disposal Technology in the next section, is the possible accumulation of heavy metals (one of which is mercury) in soils in which sewage sludges are used as an additive.

Sector III, which includes miscellaneous unregulated mercury sources, considers emissions from the numerous applications of fossil fuels in the economy; it also includes the item of livestock manure. This manure, which is estimated to account for losses of almost 18,000 kg of mercury per year, primarily to land, represents about 1 percent of the total mercury losses in the nation. However, this loss is in a dilute form and is generally restricted to areas of low population. Also, the livestock industry is actively pursuing means of preventing animal discharges from reaching public watercourses where they might have serious consequences (the emphasis in this search, of course, is on disease and BOD). For these reasons it did not seem profitable to investigate this particular "technology."

Of the emissions associated with fossil fuel consumption, electric utilities account for the largest portion--over 55,000 kg per year. Most of this is emitted to air. This usage includes natural gas (which is on the decline) and fuel oil and coal (which are on the upswing). Electric power utilities are likely to become even more important as emission sources in the future as coal, which typically has the most mercury of any of the fossil fuels on a weight basis, comes into more prominent use. Hence utilities were selected for technological evaluation.

Fossil fuels are also used for residential and commercial heating and in miscellaneous industrial applications. While these uses represent a significant source of mercury emissions to the environment (again primarily to air), these emissions in general are so diffuse and individually small that the possibility of controlling them at the source of release is poor. Hence it was decided that further study of these sources was not warranted.

Refineries, which process crude oil containing traces of mercury, and coke ovens, which destructively distill coal containing mercury, represent a relatively small source of mercury emissions. Moreover, these emissions are somewhat controlled by the emission control devices or vapor recovery systems that accompany each process. Therefore, emphasis upon mercury release and control did not seem warranted, and these sources were dropped from further consideration.

It appears that a fair quantity of the mercury in crude oils remains in the residuals following distillation; these residuals directly or indirectly supply tars and asphalts for numerous applications, such as highway and building construction. We hypothesize that in such usage a fraction of the mercurial content is released each year by continuing erosion; most of this eroded material would end up on a land surface, but some of the mercury would reach watercourses. (Certainly a portion of the mercury in the 11,700 kg estimated to be present in urban runoff comes from this source.) Although the slow loss of mercury from tar and asphalt surfaces might be of concern in some special cases, we cannot see that there would be serious consequences in general, because of the very diffuse nature of this loss. Perhaps of most concern would be direct losses to watersheds, but we estimate that such loss is relatively small; in addition, new highway construction techniques tend to channelize runoff to minimize possible pollution of receiving waters.

In Sector V, manufacturing and processing, the chlor-alkali industry clearly predominates as the major contributor of mercury emissions. Further consideration of this technology and of possible regulatory controls was indicated. Losses from other manufacturing activities involving mercury (these include catalyst, paint, pesticide, and pharmaceuticals manufacture) were found to be surprisingly low. The apparent bases for this finding were that the size of these manufacturing facilities is small (allowing better management of emissions), the quantities of mercury are low, and the high cost of the mercury itself leads to close attention to control of losses. Nonetheless, because the manufacture of mercurials is an essential intermediate step in control of mercury throughout the economy, these technologies were selected for study.

Processing, which included paint formulation, catalyst usage (such as in vat dye manufacture and vinyl chloride production), was dominated by the large "other" category. This "other," or miscellaneous, use was found to consist of many small, diverse uses, often by small manufacturers or processors; consequently losses are very difficult to trace. However, it can be assumed that since such usages are widespread and diverse, there will be no appreciable local concentrations. Hence no attempt was made to trace final usages or to discuss the technologies involved with such usage. It may well be that, since the "other" category represents a considerable mercury loss to the environment, a toxic hazard label might be required for sale of mercury and its compounds to such consumers. Such a label would state the hazardous nature of the material and emphasize the importance of proper disposal of wastes.

Electrical manufacturing, which includes tubes, switches, lamps, and batteries, releases relatively small quantities of mercury to the environment in the manufacturing process. (A great deal of internal recycling is characteristic of these industries.) Nevertheless, because these industries represent a major source of final disposal losses, it was decided to look further at their technologies and perhaps to determine if regulatory actions might be taken at the manufacturing level to reduce the quantities of mercury which ultimately enter the environment from these products.

In Sectors VIIIA and VIIIB, the final consumption of various electrical products accounts for very large losses in final dispoal--primarily to land. Hence these uses were lumped together under final disposal, which is a primary concern.

Pesticide usage accounts for rather substantial losses, particularly in nonagricultural applications, and considerable quantities of mercurial pesticides may move to receiving waters. Both agricultural and nonagricultural applications were considered in the technology assessments.

Laboratory usage, while relatively small, was believed to be another point where changes in technology might well reduce the quantities of mercury emitted to the environment. Therefore, laboratories were also considered in the technology assessments.

Pharmaceutical usage represents fairly substantial losses of mercury to water. This usage is already slight, and demand for mercurial drugs seems to be dropping as new and equally effective substitutes are discovered. Even so, it seemed advisable to consider trends in pharmaceutical usage in the technology assessment.

The use of mercurials in paint is decreasing, and an EPA action is now under way to curtail this usage even more. However, this action has drawn strong criticism from the paint industry and others. Hence the technology of paint and the implications of regulatory actions were considered.

IV

TECHNOLOGY ASSESSMENT

INTRODUCTION

The URS inventory identified a number of man-related sources of mercury which can and do enter the environment. All of these sources can be identified in terms of an SIC category. Each of these industries (including those in the trades and services) can be identified with respect to a technology or process involved. In this section these technologies are described, with emphasis on the mercury emissions that accompany the technology and on changes foreseen in the technology by the year 1983.

Technologies are discussed by sector, as described in Section III of the report. A detailed technology assessment is reported only for major contributors for which regulatory controls might prove advantageous. Because the concern here is focused on loss of mercury to the environment, the technologies of the individual industries are described only in general terms and for a typical facility or case. (Minor technologies are generally not discussed.)

Composite technologies are described by use category. This presentation considers those industries and users of mercury that are found in several sectors and possibly in disparate geographical locations, but that are related to a single use category. Paint is an example of such an industry: phenylmercuric acetate (PMA) as a preservative is discussed under mercurial compound manufacturing, and the losses in a typical facility are described. But PMA is used by many paint formulators across the nation, and additional losses occur in the formulation process. Finally, paint is sold to and used by a large segment of the population, and the emission characteristics for such usage are, again, different. Hence, in this presentation the overall losses as of 1973 at each of these various steps, for the entire paint industry, are aggregated to clearly identify the point of major losses, and to indicate where control measures might be of value.

Finally, 1973 and 1983 technologies and emissions are compared, to see what possible requirements for regulatory actions may arise. Since the concern in this entire report section is to provide an overview of many industries and many emitters, a broadbrush approach must be taken.

In the discussion of technology by facility, the background of the industry of interest is given, including its relative size and importance in the economy, its general location, and regulatory status with respect to mercury (if any). Pertinent references are cited to give additional information to the interested reader.

Facility sites are also discussed. For mining and manufacturing, where the number of sites is relatively small and where information is available, tabular data are given, including name of company, location (county and state), estimated production or output, and type of process used. While these data are generally reliable, many have been derived from a variety of sources whose agreement often seems to be merely fortuitous. In many cases, particularly with respect to production and processes, the figures are best estimates.

Next, the 1973 (current) technology is shown in a simplified flow sheet which indicates only the basic process or technology most commonly found in that industry--that is, a typical facility. Superimposed on this technology is a best estimate of mercury input and losses throughout the process. For simplification, and to allow the reader to readily compute fractional losses throughout the process, we have used a nominal input such as 100 or 1,000. These inputs are tied in each case either to a specific plant size or to a specific usage value. Outputs always equal inputs; no unaccounted losses have been recognized, even though such losses are frequently encountered in the real world.

The 1983 (projected) technology discussion presents a similar flow sheet but includes our best estimate of changes that may occur during the 1973-1983 period and of the possible effects of emissions of mercury to the environment. Often the changes are less in the technology than in the pollution control which is exercised. At best it is difficult to forecast technological changes. Therefore we have generally adopted the procedure of considering that the latest and best technology available (that is, in 1974) in terms of minimizing mercury losses or emissions is that which can and will be generally utilized in 1983. This may be a bit optimistic, but it is equally possible that regulatory requirements and technological advances may result in even greater reductions than those indicated.

Alternative processes or products which could be substituted to either reduce or eliminate the use of mercury are discussed briefly. In most cases, unless the transition is already under way (as in pesticides), alternative technologies which are only now appearing would be unlikely to have much impact by 1983. However, where a novel or interesting technology has been encountered, it is mentioned.

In a final subsection the estimated emissions for 1973 and 1983 by all users of a particular technology are presented. In some instances, high and low forecasts are included to account for variations which are foreseeable. Usually the 1983 estimates do not take into account market increases, since these would be small in comparison with errors which otherwise accompany the technological forecast. In some cases, the values for the 1973 emissions may differ slightly from those derived by the URS inventory (see Section III). These differences usually reflect modifications based upon better information obtained after the completion of the inventory, but in no way affect the overall findings of the report.

MICROTECHNOLOGIES

Sector I - Mercury Input

Mercury Mining and Refining (SIC 1092)

Cinnabar ores (which have an average mercuric sulfide content of less than 5 pounds per ton of ore) are refined by heating the ore in a furnace and condensing the mercury vapors that are released. Mining and refining operations are nearly always adjacent to each other. Major mercury-containing ore bodies are found primarily in the Western states, although some deposits are found elsewhere. At present, mining is largely concentrated in California and Nevada.

Domestic mercury production has plummeted from a high of 29,640 flasks in 1969 to 2,131 flasks in 1973 (Ref. 37). This decrease is primarily attributable to the imposition of regulations on the quantity of emissions allowed and to the general decrease in the price of mercury, from a high of about $600 per flask to around $250 per flask. As will be discussed later, the introduction of new technology and increased economic incentives could rapidly reverse this picture. Industrial consumption of mercury decreased somewhat over the 1969-1973 period, but there is still a gap between domestic production and demand which has been filled by imports from other producing nations. Secondary mercury (from recycling)* and release of mercury from stockpiles are also important supply sources.

The U.S. Geological Survey estimates that mercury is one of the scarcest domestic natural mineral resources (Ref. 39). It is estimated that domestic resources can supply approximately 10 percent to 35 percent of the minimum anticipated cumulative domestic demand through the year 2000. However, this estimate is price-sensitive, and the same source indicates that if the value of mercury were to rise sharply, the minable reserves would almost triple.

In April 1973, EPA promulgated regulations permitting the release of no more than 2.3 kg (5.1 lbs) of mercury per 24 hours for any size of operation. For the mining and refining industry as a whole, it has been estimated that 2 percent to 3 percent of the mercury is lost as vapor from stack emissions (Ref. 13).

In addition to the publications noted above, additional in-depth information on mining history and development, particularly for the State of California, can be found in Refs. 40 and 41.

Production Sites. Table 18 lists the U.S. mercury mines which were active in 1973 and their estimated production rates. Since production rates were at an all-time low in that year, it is obvious that a number of mines were shut

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* The mercury reprocessing industry has not been identified as an important contributor of mercury to the environment and therefore has not been considered in detail in this study. Clark and Fulkerson (Ref. 38) conducted a survey in 1968-1970 of this industry and their report provides some interesting and definitive information on the location of reprocessors and the source of scrap.

TABLE 18. - Production of U.S. Mercury Mines in 1973

Mine	County	State	Estimated Annual Production (flasks)
New Almaden	Santa Clara	California	720
Guadalupe	Santa Clara	California	
Chilino Valley	Marin	California	80
Corona	Napa	California	110
Oat Hill	Napa	California	
Manhattan-One-Shot	Napa	California	
Mt. Jackson	Sonoma	California	250
Culver-Baer	Sonoma	California	
Abbott	Lake	California	59
Cardero	Humboldt	Nevada	678
Ruja	Humboldt	Nevada	
Study Butte	Brewster	Texas	180
Alice and Bessie	Kuskokwim	Alaska	54
Total			2,131

Source: Ref. 42.

down; if the economic climate were suitable these, as well as the presently operating mines, could undoubtedly become more active. To assess the properties which might become active under such a situation, we compared the largest mines reported in the Bureau of Mines Mineral Yearbook in 1971 with those reported in 1966 (Ref. 43). The turnover in mines is highly volatile. Of the 24 mines producing 100 or more flasks each in 1966 (five of these produced 1,000 flasks or more), only five are retained on the list in the 1971 census. Of the 13 producing mines in 1973, all were on the 1971 list, although their production in all cases was greatly reduced.*

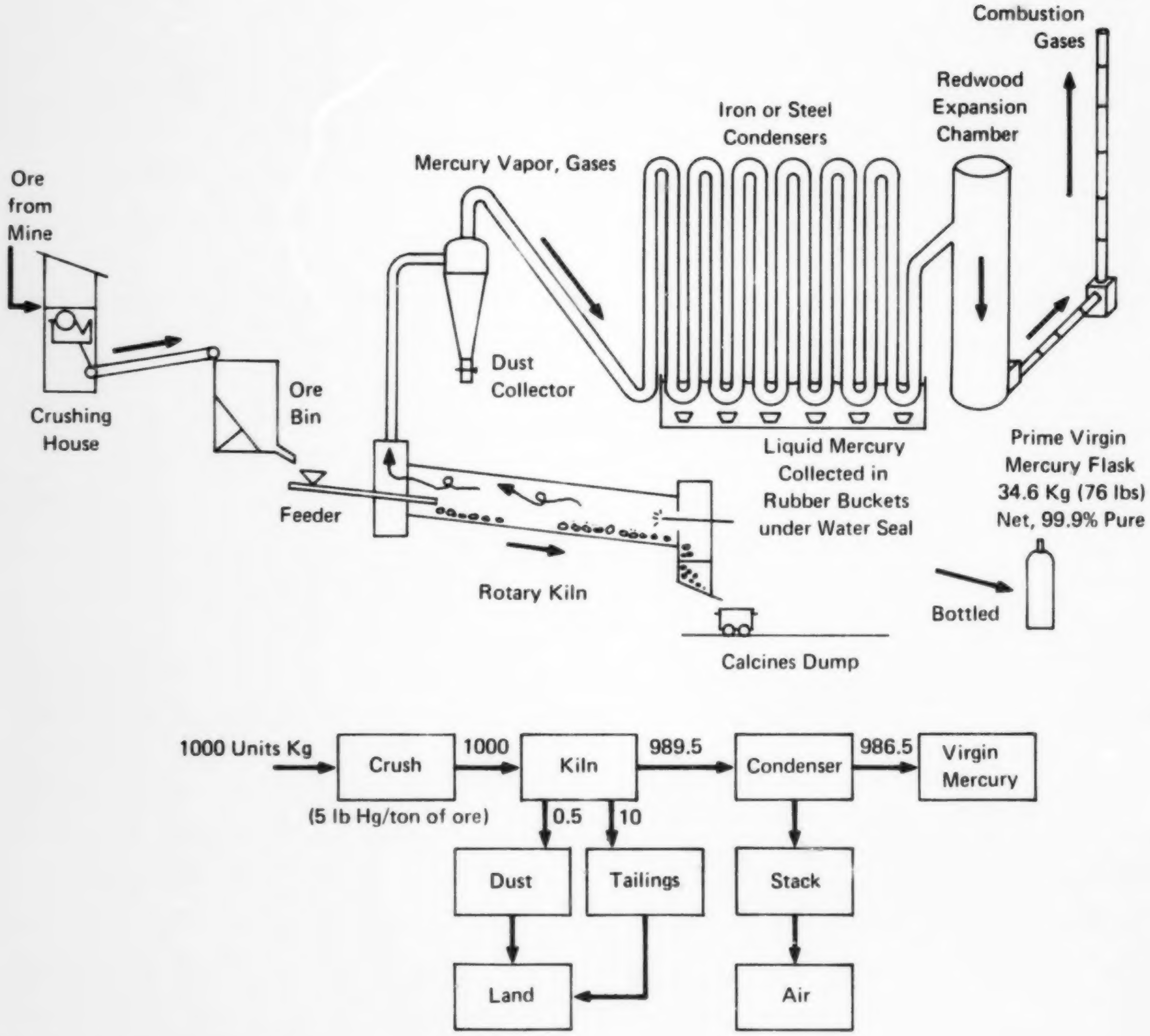
Future production of mercury in the United States is projected by some sources (including the Bureau of Mines) to remain near its 1973 low point. However, a very large mine has recently opened in Humboldt County, Nevada. The McDermitt Mine, which will be described in greater detail below, is expected to produce at least 20,000 flasks per year of virgin mercury, with a maximum capacity of up to 60,000 flasks per year. This large mine will obviously have a significant effect on both domestic and world markets.

1973 Technology. Figure 22 is a flow diagram of a typical mercury recovery unit in operation in 1973.** The ore may be obtained by either surface or underground mining and in recent years has contained about 2.3 kg (5 lbs) of mercury per ton of ore. Dust from the mining operation is generally a very minor problem and since the tonnages are low, emissions from this source are trivial (estimated in Ref. 12 to be less than 0.02 ton annually). Generally, the ore is crushed and fed from a storage bin into a rotary kiln (in a few locations, screen or table concentration is employed). Hot gases are fed into the lower end of the kiln; the ore is thus heated to well over 1,200°F and the mercuric sulfide is decomposed with an efficiency of about 96 percent. Mercury

---

* A small amount of mercury is recovered as a by-product from a gold mine in Eureka County, Nevada and from a zinc smelter in Monoca, Pennsylvania.

** Although the size of the units involved for any given operation may vary considerably, the same basic configuration is used in all recovery facilities.


Ore
from
Mine
Crushing
House
Ore
Bin
Feeder
Mercury Vapor, Gases
Dust
Collector
Iron or Steel
Condensers
Redwood
Expansion
Chamber
Combustion
Gases
Rotary Kiln
Calcines Dump
Liquid Mercury
Collected in
Rubber Buckets
under Water Seal
Prime Virgin
Mercury Flask
34.6 Kg (76 lbs)
Net, 99.9% Pure
Bottled
1000 Units Kg
Crush
(5 lb Hg/ton of ore)
1000
Kiln
0.5
10
989.5
Condenser
986.5
Virgin
Mercury
Dust
Tailings
Stack
Land
Air

SOURCE: Ref. 40; URS Research Company.

Figure 22 FLOW DIAGRAM OF MERCURY RECOVERY USING 1973 TECHNOLOGY

vapor, sulfur dioxide, combustion products, and dust are then passed off. The dust is separated in a cyclone unit and the vapors are passed through a simple water-cooled iron or steel condenser. Liquid mercury is collected as shown on Figure 22 and is bottled on-site in 34.4-kg (76-lb) flasks. Exhaust gases contain sulfur dioxide and traces of mercury vapor (which are not allowed to exceed 2.3 kg per day total discharge, by EPA standards) and are then discharged through a low stack. The calcined tailings are collected and dumped in a nearby waste pile; they typically contain about 5 ppm of residual mercury (Ref. 40). The tailings do not appear to present any leaching problems. The water used in the condensers does not come in contact with the mercury and is discharged or reused. The mercury exhausted from the stack can be assumed to remain primarily in the air, although there is doubtless some local deposition on the land surface; however, no harmful effects from this have been reported.

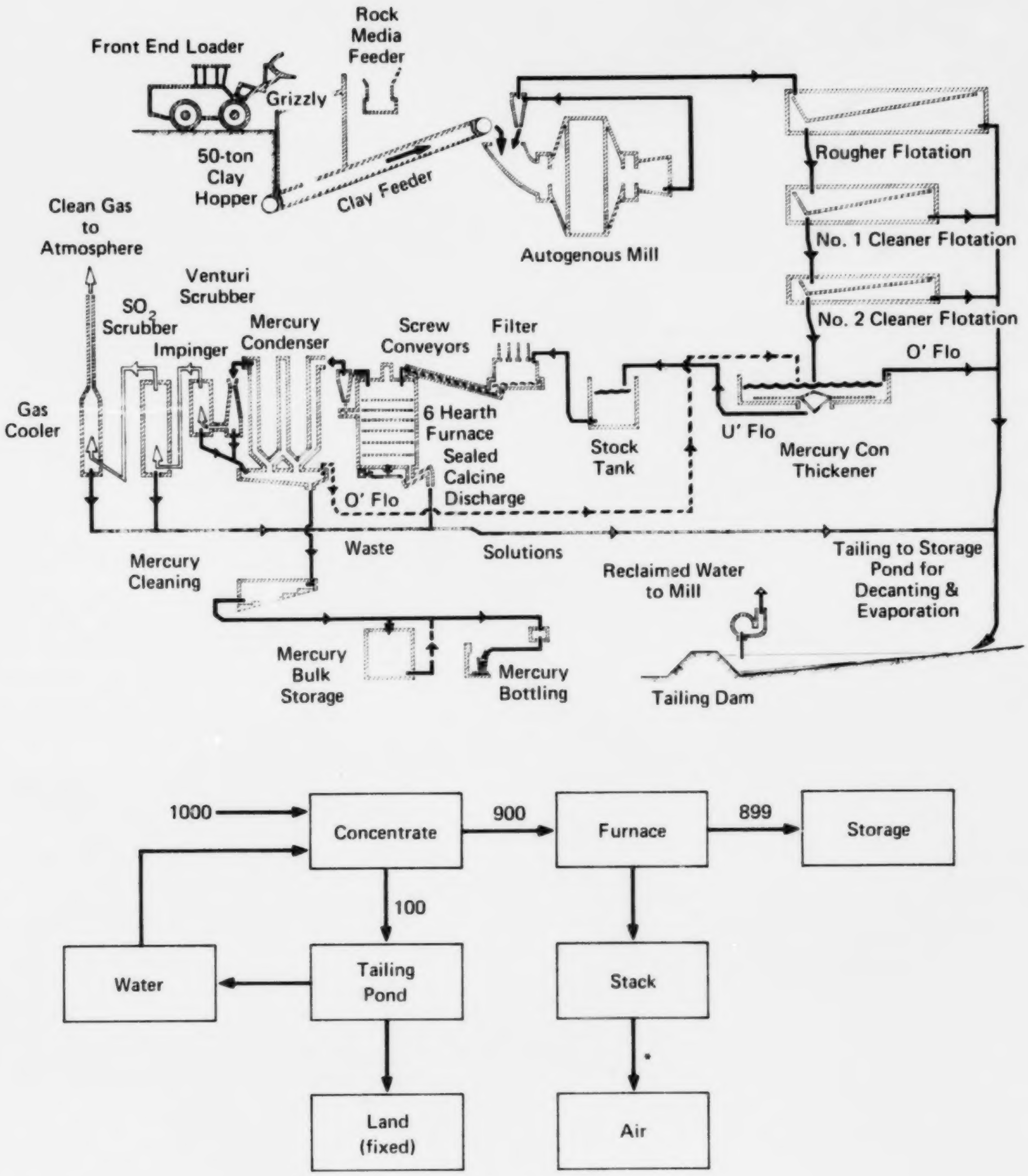
In the past, some very small operations have relied on the retort, or batch, processing of the ore. These operations are less efficient and probably are not in use at all today.

The simplicity of recovering mercury using the modern technology, coupled with low operating costs when controls were less rigid, accounts for the many small operations that were active in the recent past. Many marginal operations were activated briefly in response to higher prices and were just as quickly abandoned when prices declined.

1983 Technology. Figure 23 is a flow diagram of a mercury recovery unit which can be considered the prototype for 1983 technology. This flow chart is for the new McDermitt Mine, which has several unique features. The ore, which has an unusually high mercury content (about 4.6 kg per ton), is obtained from an open pit.* After being fed through crushers and a mill, it is concentrated

---

* Added emissions resulting from open pit mining techniques (as contrasted with the more conventional underground techniques) are unlikely. Emissions resulting from dust are trivial and can be easily controlled. The vaporization of mercury or its compounds from surface works is predicted by McCarthy (Ref. 18) to be of the same order as vaporization from the underground deposits.


Front End Loader
Rock
Media
Feeder
Grizzly
50-ton
Clay
Hopper
Clay Feeder
Autogenous Mill
Rougher Flotation
No. 1 Cleaner Flotation
No. 2 Cleaner Flotation
O' Flo
Clean Gas
to
Atmosphere
Venturi
Scrubber
SO2
Scrubber
Impinger
Mercury
Condenser
Screw
Conveyors
Filter
Gas
Cooler
6 Hearth
Furnace
Sealed
Calcine
Discharge
O' Flo
Stock
Tank
U' Flo
Mercury Con
Thickener
Waste
Solutions
Mercury
Cleaning
Reclaimed Water
to Mill
Tailing to Storage
Pond for
Decanting &
Evaporation
Mercury
Bulk
Storage
Mercury
Bottling
Tailing Dam
1000
Concentrate
900
Furnace
899
Storage
100
Water
Tailing
Pond
Stack
*
Land
(fixed)
Air

* Maximum discharge of 2.3 kg (5.1 lbs)/day. For a production rate of 2,000 kg/day of mercury (equivalent to 20,000 flasks per year), the discharge to air represents a loss of 0.1%.

SOURCE: Placer-Amex Corporation; URS Research Company.

Figure 23 MERCURY RECOVERY USING 1983 TECHNOLOGY

by flotation processes to about 60 percent mercury content. It is then fed at a rate of some 2,200 kg (1,000 lbs) per hour through a six-hearth furnace and the calcined tailings are discharged, through a seal, to a waste solution system and carried to a tailing pond for permanent storage. The reclaimed water is returned to the mill for further use. (All makeup water comes from underground wells.) The vapor from the furnace goes through tube condensers that continuously collect most of the mercury, which is then fed through a cleaning process to bulk storage (a unique feature of this mine is that it will use 1,000-kg shipping containers).

The vapor is further cleansed of mercury and the sulfur dioxide is removed; final traces of mercury are removed in a refrigerated gas cooler (utilizing the principle that mercury is very insoluble in air at temperatures of less than 100°F) and are discharged to the atmosphere. The discharge is designed to meet the EPA standard of 2.3 kg per day maximum. Although the technology used in this new mine is not yet proven, it appears to meet high standards in minimizing discharges to the environment. The cost of the mine and facilities construction was approximately $9 million, according to the developers (Placer-Amex Corporation).

The technology outlined above for 1983 obviously applies only to new installations. Capital costs to control emissions for installations using 1973 technology are estimated to range from $228,000 to $260,000, with annual operating costs of about one-third of capital costs (Ref. 15). The authors of Ref. 15 conclude that ". . . considering the 'fragile' condition of this industry, it is doubtful if they can sustain even minimal control costs." They also state that break-even production costs average between $300 and $400 per flask, which is well above the current average price per flask of about $250. Therefore it can be expected that small mercury producers will not be an important factor in the 1983 marketplace.

Estimated total emissions with high and low values from mercury mining and refining for 1973 and 1983 are shown in Table 19. Assuming that larger operations are the trend of the future and that stringent regulations will minimize the number of active operations, it is likely that total emissions from mercury mining and refining will not increase appreciably by 1983 despite the possibility of a 10- to 50-fold increase in production. However, if for some reason

TABLE 19. - Estimated Total Production and Mercury Emissions from Mercury Mining and Refining: 1973 and 1983 (kilograms)

Value Range	1973		1983	
	Production	Emissions	Production	Emissions
High	73,600	11,000[a]	2,000,000	21,150[b]
Low	73,600	8,290[c]	700,000	12,700[d]

Source: URS Research Company

a. Assuming 2.3 kg/day discharge from each of 13 sites.
b. Assuming 2.3 kg/day discharge from each of 15 sites.
c. Assuming a lower than allowable discharge, and averaging 3 percent of throughput.
d. Assuming 2.3 kg/day discharge from each of 25 sites.

small operators were to increase appreciably in number, they could contribute unduly to the total discharge of the industry (due to the clause in present regulations which regulates discharge by a given facility on total quantity, not as a fraction of the throughput of the facility). A simple change in the regulations, however, would suffice to correct such a situation were it to arise.

Alternative Technologies. Some study has been made of the possibility of obtaining mercury either by leaching the ore or by electrolytic oxidation of sulfide ores (the latter is a project of the U.S. Bureau of Mines). However, these processes have not advanced beyond the pilot stage and do not appear to be serious contenders for the forecast period.

Sector II - Mining

Copper Mining and Smelting (SIC 1021 and 3331)

The United States accounts for about one-quarter of world copper production. Copper is mined in eight states, primarily in the West, with Arizona alone accounting for almost half of the total U.S. production.* Copper is produced primarily from low-grade sulfide ores from open pit mines. The ores are concentrated mechanically, smelted, converted to blister copper, and finally electrolytically refined. Copper is also produced from low-grade copper oxide ores using hydrometallurgical methods which employ leaching, usually followed by electrolytic refining. Of major concern are the pyrometallurgical (smelting) methods, since they represent the most commonly used technology, utilize ores with higher average mercury content, and in the course of heating and smelting emit mercury as a vapor to air. Therefore the concern in this section is with smelter operation.

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* The URS regional inventory indicated that the copper industry (mining and smelting) in Arizona accounted for almost all of the mercury emissions to air in the state and contributed appreciably to those to land and water.

Little concrete information was found on the manner in which the mercury of copper ores is ultimately released to the environment. Attempts to discuss this problem area with representatives of the industry proved fruitless; in general the response was that mercury was not a problem in copper smelting. However, a rough estimate of the total quantities of mercury likely to be released by pyrometallurgical operations is 100 metric tons per year of mercury (as Hg). This value is based on 203,411 metric tons of ore processed in 1973, with an average mercury content of 0.5 ppm (Ref. 87 indicates a range for copper sulfide ores of 0.1 to 40 ppm).

In recent years the copper industry has invested heavily in pollution control technology to reduce sulfure dioxide (SO_2) emissions to the environment. EPA regulations requiring the industry to lower SO_2 discharges to air have also aided in somewhat reducing the mercury emissions, because the SO_2 recovery system removes a small portion of the mercury in the gas stream. Since data are not available on this removal rate, we have made estimates which are presented in the technology sections below.

Production Sites. Table 20 lists the producer, location, and estimated production for copper smelter operations in 1973. The production values for this year are fairly typical, although the industry's output fluctuates considerably from year to year depending upon demand, world supply, and labor relations.

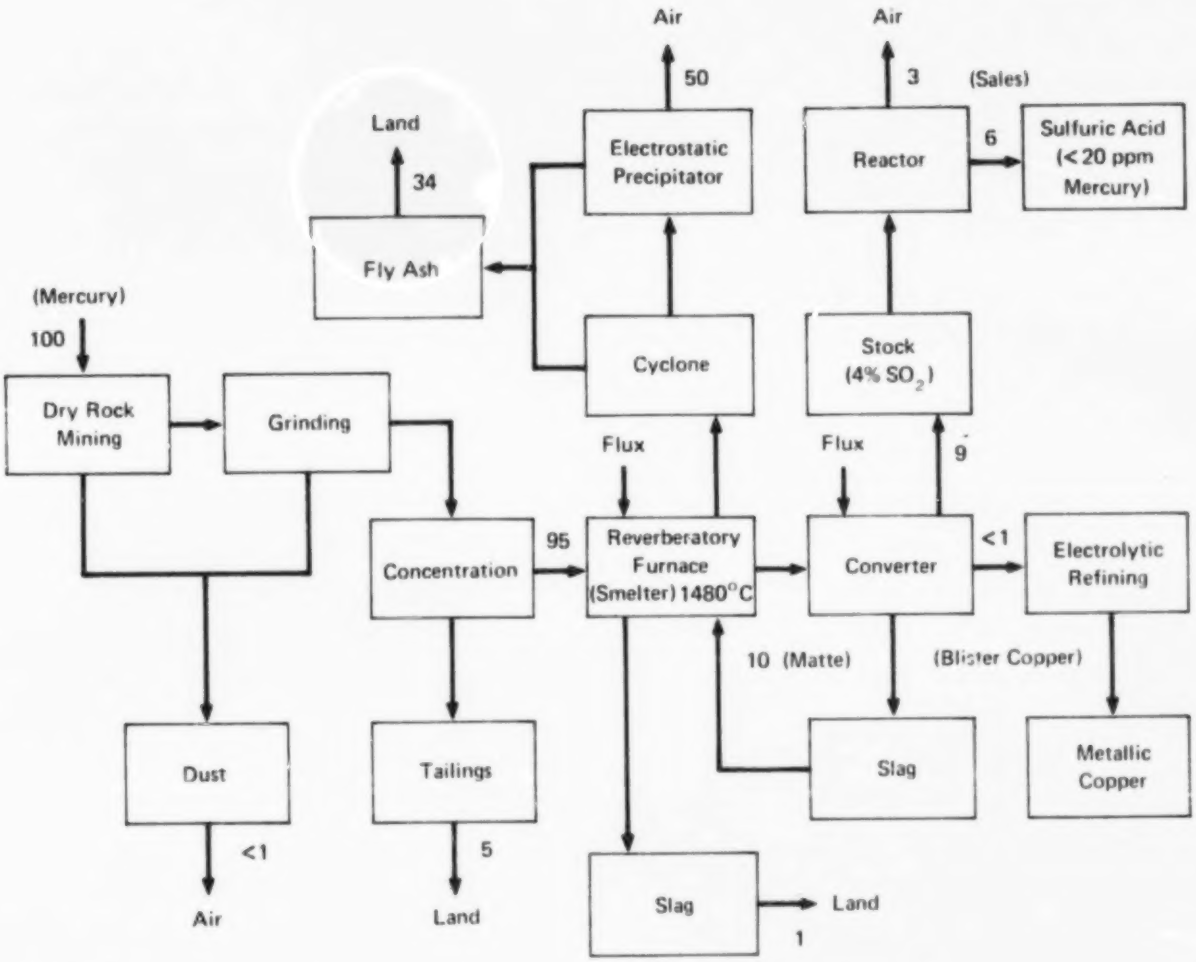
1973 Technology. A simplified flow diagram showing estimated losses of mercury in the various major processes in the mining and production of copper is presented in Figure 24. The input value of 100 could represent the 100 metric tons of mercury estimated to be present in the copper ores mined in the United States in 1973, or it could represent the flow in a typical facility.

Typically, copper ore is obtained from large, open-pit mines and trucked to the mill. A small amount of mercury is no doubt lost in the dust generated from this operation. (An additional small amount of mercury might be released directly to the air as a result of the increased degassing due to the exposure of the mineral deposit; however, as discussed elsewhere, this increase over background is small.) At the mill the ore is crushed, ground, and mixed with water and selective reagents; selective flotation concentrates the copper

TABLE 20. - Estimated U.S. Smelter Production of Copper, 1973

State and Producer	Location	Thousands of Tonnes
Arizona		791
Phelps Dodge	Morenci	
" "	Ajo	
" "	Douglas	
Magma	San Manuel	
Kennecott	Hayden	
AS&RC	Hayden	
Inspiration	Miami	
Montana		118
Anaconda	Great Falls	
Michigan		63
White Pine	Ontonagon Co.	
Nevada		96
Kennecott	McGill	
New Mexico		131
Phelps Dodge	Hidalgo	
Kennecott	Hurley	
Utah		244
Kennecott	Bingham	
Texas		100
AS&RC	El Paso	
Washington		108
AS&RC	Tacoma	
Total		1,651

Source: URS and U.S. Bureau of Mines.


Air
50
Air
3
(Sales)
Land
34
Electrostatic Precipitator
Reactor
6
Sulfuric Acid (< 20 ppm Mercury)
Fly Ash
(Mercury)
100
Cyclone
Stock (4% SO2)
Dry Rock Mining
Grinding
Flux
Flux
9
95
Concentration
Reverberatory Furnace (Smelter) 1480°C
Converter
<1
Electrolytic Refining
10 (Matte)
(Blister Copper)
Dust
Tailings
Slag
Metallic Copper
<1
5
Air
Land
Slag
Land
1

SOURCE: URS Research Company.

Figure 24 1973 TECHNOLOGY FOR COPPER MINING AND SMELTING (showing mercury input and output) content in the froth--the concentrate--which is then recovered. The worthless residue (gangue), which contains some mercury, is discharged to a tailing pile. The concentrate, which has about a 20-percent copper content, can then be economically moved to the smelter even if it is not located nearby.

The copper concentrate is fed into a reverberatory furnace (smelter) which is heated with hot combustion gases and which is also charged with slag from the copper converter and with limestone and siliceous fluxes. (The use of electrical furnaces, another form of smelting, to replace the reverberatory furnace is a rather recent innovation.) The operating temperature of about 1480° Celsius drives off some of the sulfur, which is oxidized to sulfur dioxide and escapes with the flue gases. Excess iron is eliminated in the slag. The copper matte, which is periodically withdrawn from the furnace, consists of a mixture of copper sulfide and iron sulfide. In Figure 24 we indicate that most of the mercury goes up the stack along with the sulfur dioxide, but that a small amount remains in the slag and some is carried forward in the copper matte. Considering the operating temperature of the reverberatory furnace, it is more likely that almost all of the mercury is emitted from the stack at this point, but for want of definitive information, the division shown in the figure was used.*

The stack gases from the reverberatory furnace are approximately 1 percent sulfur dioxide (SO_2); this is too dilute for economical production of sulfuric acid. On the other hand, the stack gases from electric furnaces usually contain 3 percent to 4 percent SO_2, from which sulfuric acid can be economically produced. The gases from the furnace are passed through cyclonic dust collectors and electrostatic precipitators. Thus, an estimated two-thirds of the mercury content is released to the air (through the typically high stacks used by copper smelters) and the remaining one-third is assumed to be caught in the fly ash and deposited on land.

---

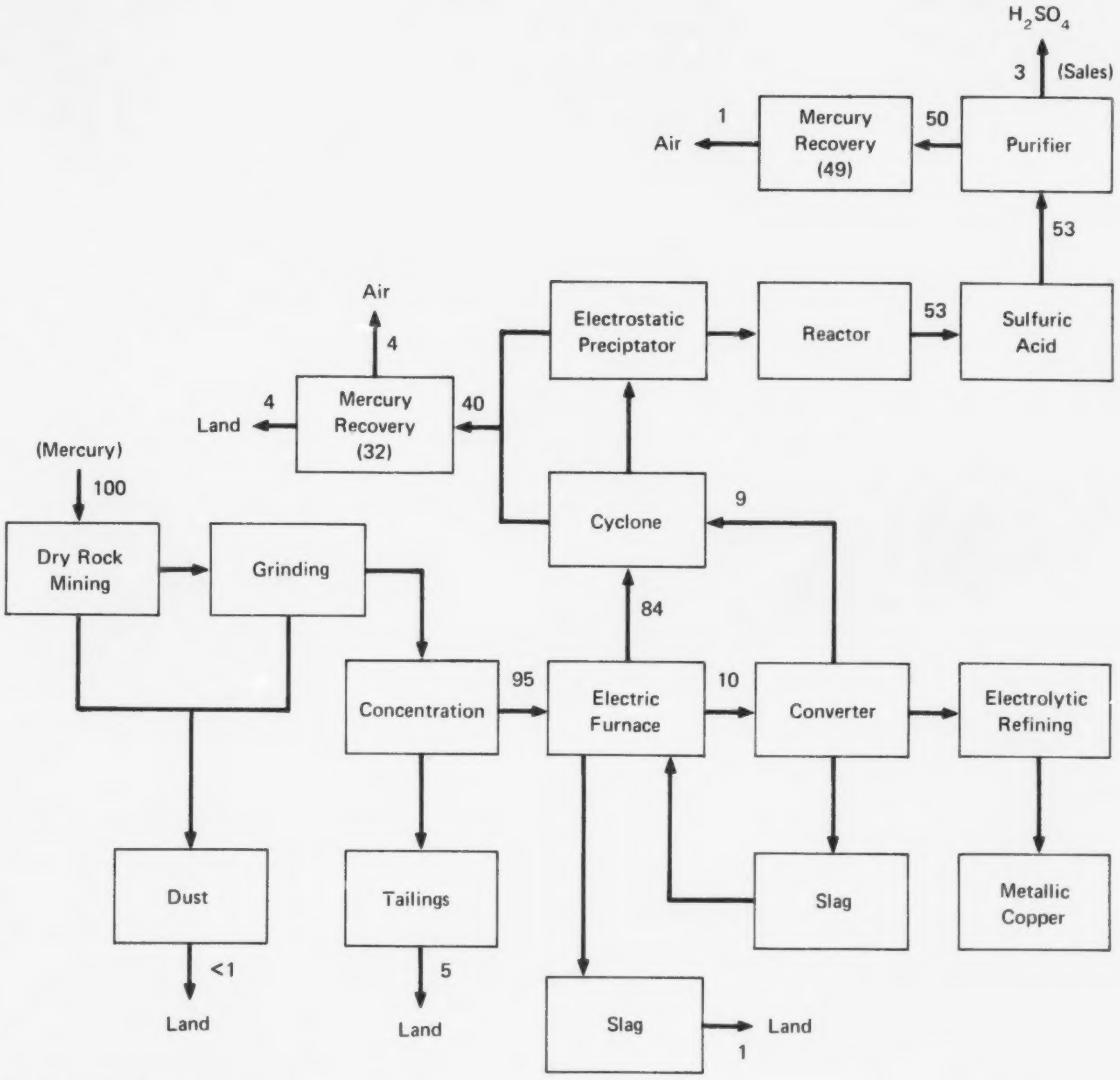
* Older technologies often had a roasting step prior to the smelter to reduce both the sulfur and iron contents to desired levels. Roasting is rarely used in newer installations, although it does have the advantage of producing a more concentrated sulfur dioxide stack gas which is more readily converted into sulfuric acid.

From the smelter the molten matte is transported to the converter, where it is treated with air or oxygen which reacts with the copper sulfide to discharge SO_2 (in concentrations of about 4 percent out the stack). As part of the conversion process, iron sulfide is oxidized, creating additional SO_2, and the iron combines with the siliceous flux to form a slag which contains copper and other precious metals and is returned to the reverberatory furnace. The resultant "blister" copper is 99.5 percent pure and is normally further purified, usually by electrolytic refining. It can be assumed that at this point the mercury content of the copper is virtually nil, since most of the mercury was exhausted to the stack during the smelting stage in the reverberatory or electric furnace. Any remaining mercury in the gases would find its way into the sulfuric acid, probably in concentrations of less than 20 ppm. A minute quantity of mercury would go out the stack.

It should be noted that approximately 80 to 90 percent of the mercury exhausted remains airborne for at least 10 km downwind and may become part of the global burden (Ref. 16). However, the remaining 10 to 20 percent is assumed to be deposited evenly on either land or water surfaces. At least half of this mercury eventually reaches the watercourse, either directly or by runoff from land surfaces (Ref. 44).

1983 Technology. Figure 25 is a flow diagram of the technology which will probably be in use in 1983 for the pyrometallurgical processing of copper. Again, an input of 100 units of mercury is assumed, since better forecasts are not available. The major changes for 1983 will occur in the pollution control technology associated with the treatment of the stack gases and in the use of electric furnaces which produce a higher SO_2 gas concentration. In this flow diagram it is assumed that the SO_2-laden gases from the smelter and converter are combined and that a considerably larger fraction of these gases is then reacted to form sulfuric acid. The remainder of the stack gas stream undergoes further treatment for recovery of mercury, and discharges to air and land are greatly reduced. Mercury is also recovered from the sulfuric acid produced, thus adding to the revenues of the facility.

While it is impossible to describe in detail the technology likely to be used in 1983 for control of mercury emissions and for recovery of mercury itself,



H_2SO_4
3
(Sales)
1
Air
Mercury Recovery (49)
50
Purifier
53
Air
4
Electrostatic Preciptator
Reactor
53
Sulfuric Acid
4
Land
Mercury Recovery (32)
40
(Mercury)
100
Cyclone
9
Dry Rock Mining
Grinding
84
95
10
Concentration
Electric Furnace
Converter
Electrolytic Refining
Dust
Tailings
Slag
Metallic Copper
<1
5
Land
Land
Slag
Land
1

SOURCE: URS Research Company.

Figure 25 1983 TECHNOLOGY FOR COPPER MINING AND SMELTING (showing mercury input and output) current literature suggests various possibilities. For example, the Gortdrum mines in County Tipperary, Ireland, now recover mercury from copper concentrates. However, more interest has been displayed in a technology involving recovery of mercury from flue gases. For example, Ref. 45 suggests the use of a countercurrent sulfuric acid wash to recover up to 90 percent of the mercury content of the stack gases. The Outokumpu Oy zinc plant at Kokkolla, Finland, is reportedly recovering 600 flasks per year of mercury as a by-product of the roaster gases in a process which should be adaptable for copper smelting (Ref. 46).

As indicated above, the mercury content of the stack gases may be removed prior to the sulfuric acid unit. However, if such technology is not employed, mercury will appear in the concentrated sulfuric acid. This problem has apparently been successfully attacked by the Bunker Hill Company, which reports that it has reduced the mercury content of by-product sulfuric acid to less than 1 ppm at its Coueur d'Alene (Idaho) smelter (Ref. 47). Other processes are reported to be under development for removal (and recovery) of mercury from by-product sulfuric acid.

Alternative Technologies. Smelting appears to be the preferred route for extraction of copper sulfide ores. However, a hydrometallurgical approach has been proposed by the Power Plate Corporation of Salt Lake City (Ref. 48). In this patented (but not yet proven) process, the sulfide ore is mined, crushed, ground, concentrated, and then processed in the Power Plate cell. "Here, copper dissolution and electrodeposition occur simultaneously at high current densities, and in the presence of ferric sulfate, sulfuric acid, and oxygen." The author claims that this process results in a cost of $376 per ton of installed capacity per year, which is only 34 percent of the smelter cost it replaces. However, the likelihood is remote that this process, even if proved commercially feasible, will become an important part of the production pattern by 1983.

Implications. Table 21 shows the estimated total emissions from all U.S. copper smelters to various receiving media for the year 1973 to 1983. Drastic changes are forecast which are primarily related to the continuing concern of the copper industry with cleaning up major pollutants, especially sulfur dioxide. It is presumed that this concern will coincide with the realization that recovery

TABLE 21. - Estimated Emissions from Copper Smelting, 1973 and 1983
(tonnes)

Receiving Medium	1973	1983
Air	53[a]	3[a]
Land	40 (2.6)[a]	8 (0.15)[a]
Water	(2.7)[a]	(0.15)[a]
Product	7	4
Reclaim	-	85
Total	100	100

---

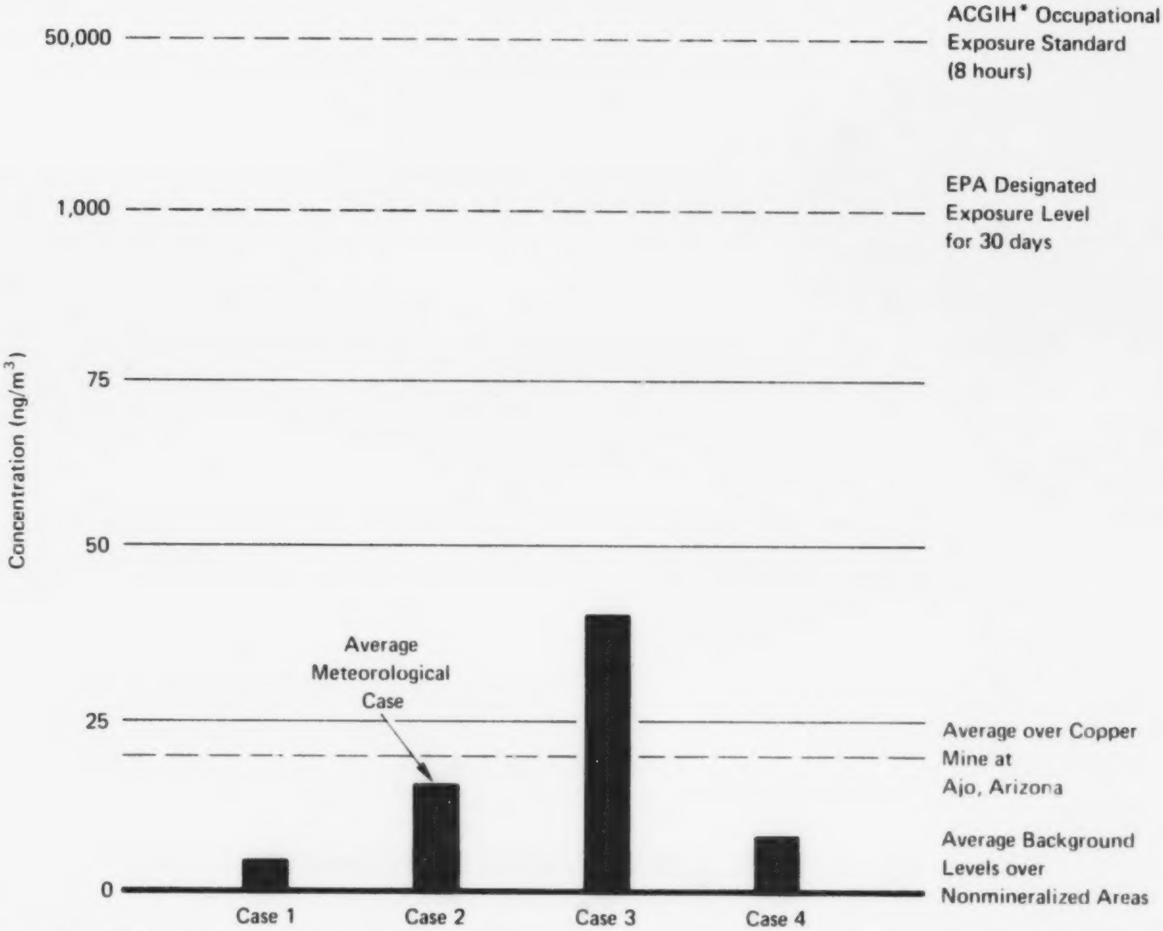
a. Ten percent of emissions to air are expected to fall out locally and to be equally distributed between land and water.

Source: URS Research Company

of the mercury associated with SO_2 is economically feasible and will serve to improve the environment. If this forecast is correct, an estimated 85 percent of the mercury currently lost (primarily to air and land) may be reclaimed for resale.

However, it must be noted that a case cannot be made for regulation of these mercury emitters on the basis of safety or hazard alone. To assess the potential airborne hazard which might be represented by each smelter, isopleths of mercury vapor concentration were constructed from the results of a simple Gaussian diffusion model. (Complete results are shown in Appendix E.) Three runs were made; two were of maximum short-term concentrations under worst-case and average meteorological conditions, and the third was for an 8-hour averaging time under worst-case meteorological conditions. Pertinent stack information was provided by the EPA National Emission Data System (NEDS) Program. The assumed mercury content in the stack gas was approximately 167 micrograms per cubic meter ($\mu g/m^3$), corresponding to an average concentration in the ore of 0.5 ppm, all of which was assumed to reach the atmosphere (i.e., the cyclone and electrostatic precipitators did not remove any of the mercury and all of it was volatilized during the smelting process in the reverberatory or electric furnace).

As shown in Figure 26, all three cases studied exceed the average background level for nonmineralized areas. However, only the short-term worst case exceeded the background level expected for mineralized areas such as would be found near copper smelters ($\sim$30 ng/m^3 near Ajo, California; see Ref. 18). And most importantly, even the maximum recorded level, at approximately 2.5 km downwind, was approximately 1/25th of the EPA designated exposure level for 30 days of continuous exposure. Thus, in light of the fact that copper smelters are located in the very lightly populated areas, neither the quantity of material emitted nor the population exposed to these somewhat elevated (above background) levels is actually of great concern.



* American Conference of Government Industrial Hygienists.

SOURCE: URS Research Company.

Figure 26 MAXIMUM MERCURY VAPOR CONCENTRATIONS FOR CASES 1-4

However, since it is suspected that continued deposition of toxic materials from airborne plumes can lead to an accumulation of such materials in the soil,* an estimate of such a cumulative effect was made. Certainly, elevated values for land have been observed around copper smelters (greater than 200 ppb versus 71 ppb for background on similar terrain; see Ref. 29), which suggests that buildup may be occurring. In our estimate (see Appendix E) the principal assumptions were that 10 percent of the mercury in the plume reaches the ground within a radius of 10 km from the smelter, remains there, and accumulates for a period of 20 years.

Using these relatively gross assumptions and the average case shown in Figure 26, we calculate that the smelter would contribute an additional 111 ppb to the existing background of 71 ppb. By changing the assumptions somewhat to assume that 10 percent to 100 percent of the mercury released from the smelter reaches the ground within 10 km, and 20 percent to 100 percent of this remains in the soil, the range of mercury concentrations above background could be from 70 to 890 ppb. However, even the highest of these values has not been demonstrated to present a health hazard to people or animals. (Uptake by plants and presumably from there to animals is certainly likely; again, however, the impact cannot be demonstrated to be of great significance.)

Aside from the mercury that settles locally, the balance of the emissions from copper smelters is assumed to become part of the global mercury burden. Even so, the quantities involved for the area bounded by the coterminous United States are less than 10 percent of all emissions to air from man-related sources, and are insignificant in comparison with degassing emissions.

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* Lawsuits have resulted from the identified buildup of lead in vegetation and people located downwind of lead smelters. However, it is most difficult to establish the smelter as the cause of these observed effects; hence the use of the word "suspected."

Sector III - Miscellaneous Unregulated Sources

Power Plants (SIC 49110 and 4911C)

The electricity generated by power plants for transmission and distribution to consumers is obtained from several energy sources. Fossil fuels account for 81 percent, hydropower for 15 percent, and nuclear power for 4 percent of this energy (Ref. 49). Of these, the only significant unregulated source of environmental mercury pollution is fossil fuels.

Electric power is usually generated by superheating water in a boiler and passing the resultant steam through turbine generators. The three types of fossil fuels used to heat the water are coal, oil (distillates or residuals), and natural gas; these fuels account for 44 percent, 16 percent, and 21 percent respectively of total U.S. electrical power generation in 1973 (Refs. 49, 50). Local utilities' choice of fuel usually depends on what is most available and most economical in the immediate area. For example, the Appalachian and Midwest regions depend on coal as the major fuel, but the Gulf states and the Far West depend on petroleum or natural gas.

The rate at which mercury is emitted to the environment by a power plant depends on the size of the plant, the type of fuel, and the mercury content of the fuel. Mercury content varies according to geographical region and even according to layer within the fuel bed. Appalachian coal, for example, has an average mercury content of 0.2 ppm (range of 1.46 ppm to 0.07 ppm), but coal from the mountains of the West has a mercury content of 0.06 ppm (Ref. 51). In general, the national average content of mercury in fossil fuels is as follows: coal, 0.2 ppm; distillate oil, 0.066 ppm (Ref. 12); residual oils, 0.13 ppm (Ref. 10); natural gas, 0.04 ppm (Ref. 12).

The cost of petroleum and natural gas is escalating because of the depletion of domestic reserves and increased dependence on foreign supplies. Therefore, other fuel sources are being increasingly utilized for electric power generation. Coal is unquestionably the leading contender for the short term, because there are abundant reserves in the United States--estimated at 421 billion tons in 1973 (Ref. 49). The other possible energy sources are breeder and thermal reactors and oil shale deposits (in Colorado, Utah, and Wyoming). It is difficult at this time to determine what fuel source will dominate in the long term. Environmental constraints, the long lead times required for research and development, uncertainties in predicting capital investment by utilities or government, and mining constraints all combine to make forecasting in this area extremely hazardous and unreliable.

Production Sites. Table 22 lists power plant emissions by type of fuel and by state. Most large power plants are located near heavily populated and industrialized centers. Plants that use coal and natural gas tend to be very large facilities (in the megawatt generation range), but petroleum-using plants vary from small municipal to large facilities.

Most power plants in the Atlantic region use coal-fired furnaces because of the rich Appalachian coal deposits. States that rely primarily on this energy source are Florida, Georgia, Maryland, New York, North Carolina, Pennsylvania, South Carolina, Virginia, and West Virginia. The other Atlantic states balance coal use with petroleum and natural gas.

In the North Central region, power generation relies chiefly on coal, with lesser amounts of petroleum and natural gas. The leading coal-using states are Illinois, Iowa, Kentucky, Michigan, Minnesota, Missouri, Ohio, Tennessee, and Wisconsin. In contrast to the Atlantic region, the North Central region has many small municipal utility companies that rely on diesel power.

The predominant energy source in the South is natural gas, because of the rich deposits found in the Gulf states. Petroleum also supplies some Southern power generation needs. The mountain region has a relatively good balance of energy sources. The West derives most of its energy from petroleum and natural gas, since large reserves of these resources are available there.

1973 Technology. Two flow diagrams for typical power plants are shown in Figure 27. The only difference between the two diagrams is in the mercury emission factors of the fuel consumed for electricity generation. The emission factors for coal are 90 percent to air and 10 percent to land (Refs. 51, 52, 53). Natural gas and petroleum, because of their cleaner burning characteristics, emit 99 percent to air and 0.1 percent to land (Ref. 54). The principal reason for the high air emissions is the low boiling temperature of mercury--685°F

TABLE 22. - Power Plant Mercury Losses in the United States, 1972
(kilograms)

Region and State	Total Energy Output (millions of kwh)	Fossil Fuel Source					
		Coal		Oil		Natural Gas	
		No. of Plants	Mercury Loss	No. of Plants	Mercury Loss	No. of Plants	Mercury Loss
Atlantic							
Connecticut	15,619	9	15	17	537	3	<1
Delaware	5,400	5	99	4	80	4	2
Florida	67,081	4	1,598	51	1,248	33	138
Georgia	30,204	6	1,029	10	79	6	31
Maine	2,985	2	59	18	107	5	<1
Maryland	27,802	12	324	14	525	5	6
Massachusetts	29,327	0	0	33	888	18	6
New Hampshire	4,121	2	45	8	44	0	0
New Jersey	30,327	4	221	29	852	8	20
New York	68,133	22	1,209	44	1,632	18	61
North Carolina	51,162	18	3,063	6	87	7	14
Pennsylvania	96,034	33	6,994	64	447	4	5
Rhode Island	1,284	2	56	7	52	1	<1
South Carolina	17,262	9	931	21	35	6	20
Vermont	163	1	27	12	2	2	<1
Virginia	28,441	15	323	11	470	3	4
West Virginia	48,466	12	1,258	2	11	1	<1
Subtotal	523,811	156	17,251	351	7,096	124	308
North Central							
Illinois	70,214	28	2,165	48	197	18	59
Indiana	53,843	24	1,760	21	14	7	15
Iowa	14,652	23	1,159	138	10	11	49
Kansas	16,953	8	45	111	10	9	146
Kentucky	49,891	16	4,452	5	6	4	8

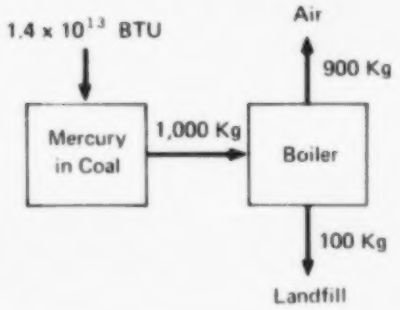
TABLE 22. - Power Plant Mercury Losses in the United States, 1972
(kilograms)
(continued)

Region and State	Total Energy Output (millions of kwh)	Fossil Fuel Source					
		Coal		Oil		Natural Gas	
		No. of Plants	Mercury Loss	No. of Plants	Mercury Loss	No. of Plants	Mercury Loss
North Central							
Michigan	57,339	26	1,482	62	147	11	48
Minnesota	15,752	19	[illegible]	114	29	6	42
Missouri	32,404	16	2,861	61	9	7	48
Nebraska	7,066	2	30	71	6	5	40
North Dakota	5,495	3	181	28	<1	4	<1
Ohio	92,553	42	4,738	47	40	5	14
Oklahoma	25,571	2	41	32	1	25	211
South Dakota	705	7	195	39	5	4	3
Tennessee	40,690	9	3,424	1	3	5	13
Wisconsin	25,096	22	759	42	10	14	23
Subtotal	508,224	247	24,146	820	487	135	719
South							
Alabama	39,550	8	1,742	3	7	5	2
Arkansas	9,539	2	69	6	55	14	59
Louisiana	39,348	0	0	31	21	27	310
Mississippi	12,141	8	1,115	8	42	10	82
New Mexico	18,192	2	124	13	9	10	48
Texas	129,912	3	267	57	21	89	1,043
Subtotal	248,682	23	3,317	118	155	155	1,544
Mountain							
Colorado	12,204	12	154	15	11	14	55
Idaho	1	1	29	3	<1	0	0
Montana	1,245	2	27	5	<1	2	1

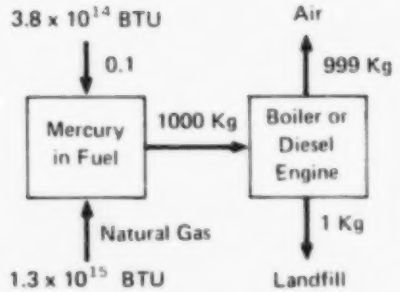
TABLE 22. - Power Plant Mercury Losses in the United States, 1972
(kilograms)
(continued)

Region and State	Total Energy Output (millions of kwh)	Fossil Fuel Source					
		Coal		Oil		Natural Gas	
		No. of Plants	Mercury Loss	No. of Plants	Mercury Loss	No. of Plants	Mercury Loss
Mountain							
Utah	2,145	4	22	13	24	4	3
Wyoming	7,065	2	206	19	2	1	2
Subtotal	22,659	21	438	55	37	21	61
West							
Alaska	1,271	1	12	28	5	11	10
Arizona	9,279	5	58	9	28	10	63
California	90,357	0	0	32	896	30	492
Hawaii	4,756	0	0	15	155	0	0
Nevada	11,441	2	27	10	2	7	33
Oregon	55	0	0	7	<1	2	<1
Washington	23	0	0	12	2	0	0
Subtotal	117,182	8	97	113	1,088	60	598
Totals	1,420,558	455	45,249	1,457	8,863	495	3,230

Source: URS Research Company, based on Ref. 49 and "Electrical World - Dictionary of Electric Utilities," 1972-1973.


1.4 x 10¹³ BTU
Mercury in Coal
1,000 Kg
Boiler
Air
900 Kg
100 Kg
Landfill

(a) COAL-BURNING PLANT


3.8 x 10¹⁴ BTU
0.1
Mercury in Fuel
Natural Gas
1.3 x 10¹⁵ BTU
1000 Kg
Boiler or Diesel Engine
Air
999 Kg
1 Kg
Landfill

(b) PETROLEUM- OR NATURAL GAS-BURNING PLANT

SOURCE: URS Research Company.

Figure 27 MERCURY LOSSES FROM TYPICAL POWER PLANTS, 1973

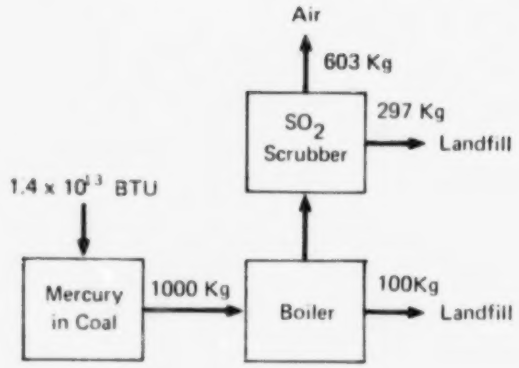
(Ref. 55). The air emissions are primarily in the metallic form, with minor losses in the oxide form. Losses to land come from bottom ash, which ranges between 4 percent and 20 percent by weight of coal (Refs. 54, 56), and fly ash (stack emissions). To date very little effort has been expended by the government or the utilities to reduce mercury losses from fossil fuel power plants.

Technology in 1983. Figure 28 is a flow diagram for the partial recovery of mercury from power plant operations. These diagrams, which represent prototypes for 1983, are patterned after a sulfur dioxide (SO_2) scrubber pilot plant operated by the Tennessee Valley Authority (TVA). The Colbert plant, which burns high sulfur coal, was equipped with a SO_2 scrubber to remove the sulfur gases from stack discharges, but preliminary tests conducted by the EPA found that it also removed about 33 percent of the stack mercury discharges (Ref. 57). The reasons for the high mercury recovery are that the scrubber removes the fly ash (total emission 0.7 kg mercury per 10^6 kg ash) and that heavier mercury vapor particles are found in the flue gas (total emission 0.08 kg mercury per 10^6 kg gas) (Ref. 10).

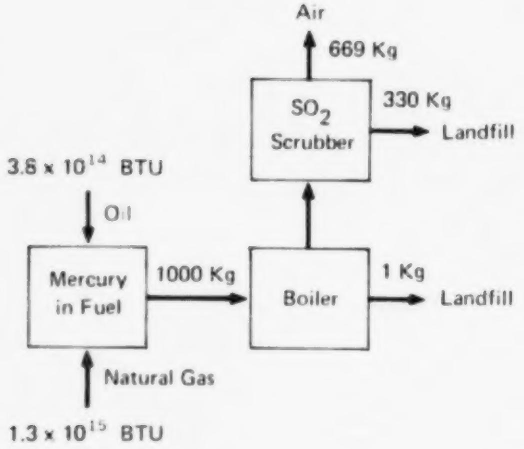
Because of increased constraints placed on SO^2 emissions to meet clean air standards, scrubbers probably will be installed on most fossil fuel power plants by 1983. This should result in about a one-third decrease in uncontrolled mercury emissions to the atmosphere. This quantity of mercury will then accrete in controlled landfills.

Fossil fuel consumption is expected to increase about 50 percent between 1973 and 1983 (at a 3.4-percent annual rate compounded), if current demands and usage continue, with coal increasing 55 percent and natural gas and oil decreasing 5 percent (Ref. 144). Mercury emissions, however, should increase only 15 percent for the low prototype technology and should decrease by 14 percent for highly developed technology. Mercury emissions are not expected to increase at the same rate as fuel consumption because mandated control of SO_2 emissions by 1983 will coincidentally lead to removal of part of the mercury.

Alternative Technologies. Due to the cost of developing an effective recovery system for mercury alone, it appears that complete mercury recovery from stack discharges will not occur in the foreseeable future. However, fuel sources which do not release appreciable amounts of mercury to the environment may be developed before the year 2000. Nuclear power (especially breeder reactors) is


Air
603 Kg
SO2 Scrubber
297 Kg
Landfill
1.4 x 10^13 BTU
Mercury in Coal
1000 Kg
Boiler
100Kg
Landfill

(a) COAL-BURNING PLANT


Air
669 Kg
SO2 Scrubber
330 Kg
Landfill
3.6 x 10^14 BTU
Oil
Mercury in Fuel
1000 Kg
Boiler
1 Kg
Landfill
Natural Gas
1.3 x 10^15 BTU

(b) PETROLEUM- OR NATURAL GAS-BURNING PLANT

SOURCE: URS Research Company, based on TVA Colbert plant process.

Figure 28 MERCURY LOSSES FROM TYPICAL POWER PLANTS, 1983

an excellent long-term possibility for supplementing fossil fuels. A minor development is that mercury is used in sterilizing the control rods in the reactors (Ref. 58). However, the chief constraints to full development of nuclear power plants are other environmental considerations--radioactive waste disposal, mine and smelter tailing wastes, plant safety, thermal heat dissipation, and so on.

Another alternative to fossil fuel usage is geothermal power. Geothermal steam has proved to be an available energy source (albeit small to date) in the United States. Mercury is released along with the spent steam, but the amounts are insignificant. Like most of the alternatives, constraints other than mercury content may limit the full development of this energy source. Also, thermal energy is not evenly distributed across the United States. Solar energy also offers an alternative to fossil fuels. The full development of this energy source, however, will require large expenditures for research and development. Other energy sources for electric power plants are possible, but are not expected to materialize in the foreseeable future.

The energy sources most likely to be used to alleviate the present shortage appear to be shale oil and coal. These materials, which are found abundantly in the United States, can be treated by a variety of processes to yield synthetic crude oil or synthetic natural gas. Although both materials contain mercury, no information is available on the fate of mercury in shale oil or coal which is converted to a synthetic product. However, based upon our knowledge of the candidate processes, we can make some very preliminary estimates about the final disposition of such mercury to the environment.

The processes for recovering product from shale oil or coal involve heating to relatively high temperatures. Since mercury boils at about 360°C (and its compounds either boil or decompose at or below this temperature) mercurials are likely to be found increasingly in the gaseous phase as the process temperature increases. For the recovery of oil from oil shale, some of the older processes (such as the U.S. Bureau of Mines gas combustion retort) which operate at over 900°C should certainly drive most of the mercury off with the combustion gases. However, some more recent processes, such as TOSCO II, operate at much lower temperatures (480°C), so that considerably more mercury is likely to be found in the residual wastes. Nevertheless, the presence of mercurials in waste from shale oil processing is of minor concern compared with the major problem of disposing of the vast quantities of wastes themselves. If oil is a major processing product, the likelihood that mercury will concentrate therein is fairly small, but if a synthetic natural gas (SNG) is a major product, the probability of mercury occurrence therein is considerably higher.

Some consideration has also been given to in situ retorting of deep-lying beds of shale. It appears unlikely that the mercury content would concentrate in the resulting oil product, and the mercury that did appear there would probably be vaporized with stack gases in subsequent refining processes.

Three general classes of coal liquefaction processes typify the manner in which mercury might be distributed to the environment. In pyrolysis processes, pulverized coal is heated at atmospheric or low pressures to release its oil content. In several such processes (for instance that developed by FMC Corporation) temperatures above 800°C are reached; this suggests that the mercury content is almost totally released, probably ending up in the gaseous fraction (which is a low heating value SNG). The TOSCOAL retorting process operates at around 500°C, so considerably more mercury may remain in the oil product or in the residual matter.

The direct hydrogenation of coal occurs at rather low temperatures (450°C) and at very high pressures (greater than 2,000 psi). Mercury would probably concentrate in the oil product, and to a lesser degree in residual matter, with little appearing in lighter fractions. In the solvent extraction of coal the temperatures are low (somewhere above 400°C) and pressures are moderate to high. Thus little mercury is likely to be found in off-gases. Mercury and its compounds are unlikely to be vaporized and as a result, most of the mercury content could remain in the waste material.

The removal of sulfur from solid fossil fuel materials is a part of the developing technology described above. Mercury can be expected to "accompany" sulfur and may be extracted with it. While the recovery of mercury from such processing does not appear feasible at this time, it should be noted that mercury is now being recovered from the sulfur residues from at least one copper mining operation (see discussion under Copper Smelting Technology). It is certainly not inconceivable that, if extensive development of shale and coal resources occurs, the recovery of the mercury content may become economically justifiable. It is most unlikely, however, that this would happen in the period prior to 1983 (see Ref. 145).

Sector V - Manufacturing and Processing

Chlor-Alkali Manufacturing (SIC 2812)

In 1973 the chlor-alkali manufacturing industry consumed 13,070 flasks (450,967 kg), or 24 percent, of the mercury used in the United States (Ref. 59). According to a report by Versar, Inc. (Ref. 60), the loss of mercury to land was approximately 7,834 flasks, or 60 percent of the mercury used by this industry. The largest loss, 6,590 flasks, occurred when the chlor-alkali sludges were deposited in industrial landfills. The remaining environmental mercury losses were to air and water, representing 672 flasks and 125 flasks respectively. The remaining 5,683 flasks of mercury consumed by the industry were used in plant expansions, system buildups, inventories, etc.

The production of chlorine gas (Cl_2) and caustic alkali (called caustic soda or sodium hydroxide) is accomplished using the mercury cell, which was discovered in 1892. However, the diaphragm cell plant (the diaphragm cell process filters a salt brine and then electrolyzes the brine without mercury to form chlorine and caustic alkali) dominated the world's chlor-alkali industry until the late 1930s. In that decade rapid progress in mercury cell technology was made by I. G. Farbenindustrie of Germany because of the growing demands for rayon-grade caustic. It was not until the end of World War II, however, that other nations realized the technical superiority of the mercury cell over the diaphragm cell. In the United States, the diaphragm cell process still dominates, but since 1945 mercury cell plants have increased. In 1945, mercury cells accounted for only 4 percent of the chlorine production in the United States; by 1959, chlorine production using the mercury cell had increased to 19 percent of the total, and by 1973 this figure had increased to 24 percent (Ref. 61). Because of recent problems with mercury discharges to the environment, however, it is not certain how much the mercury cell process will grow. The key to such growth will be the ability of the industry to control mercury emissions.

Mercury cell production of chlorine and caustic alkali is accomplished using an electrolyzer and a decomposer. In the electrolyzer a sodium chloride solution (brine) is subjected to an electric current, making use of an anode (positive pole) and a flowing mercury cathode (negative pole). Chlorine gas is evolved and collected at the anode, and a liquid alkali metal amalgam (NaHg) is formed with the flowing mercury cathode. The alkali metal is transported to a decomposer where the amalgam reacts with water to form caustic (NaOH) and hydrogen gas (from which excess mercury is removed); the purified gas is normally flared.

Production Sites. Fifteen companies in the United States used the mercury cell to manufacture chlorine in 1973. Of these, Allied Chemical Corporation, Olin Corporation, Stauffer Chemical Company, Diamond Shamrock Corporation, and PPG Industries, Inc. accounted for approximately 62 percent of the chlor-alkali production using the mercury cell process (Ref. 62). Table 23 lists the location of mercury cell plants by state and gives their approximate mercury losses to the environment in 1973.* Thirty-eight percent of the mercury loss in chlorine manufacturing occurred in the Atlantic region, 20 percent in the North Central region, and 38 percent in the South. Five states account for 54 percent of the mercury loss: New York (8 percent), Kentucky (8 percent), Alabama (13 percent), Louisiana (16 percent), and Texas (9 percent).

Most of the chlorine produced in Alabama, Georgia, Maine, North Carolina, Washington, West Virginia, and Wisconsin is used in paper production. The chlorine produced in the other states is used by the industrial chemical industry, except that in Louisiana chlorine sales are balanced between paper production and industrial chemicals.

Chlor-alkali plants are generally found on navigable rivers or near ports because chlorine is most safely and economically transported by barge. However, some users (for example paper and pulp producers) are located in rather remote areas, and since transporting chlorine for great distances is not practicel, small chlor-alkali plants, generally with mercury cell technology, are found in such scattered locations.** Larger plants (with more than 500 tons/day capacity) are more efficient and are built wherever demand and transportation factors permit.

As shown in Table 23, there are 28 plants in the United States that manufacture chlorine using mercury cells. The types of mercury cell used by these

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* The land losses shown in this table are due to sludge only. Sludge losses are singled out because the remaining losses, representing approximately 2,035 flasks, cannot be treated and remain fixed through 1983.

** The direct production of 50 percent caustic which is also used by the paper industry from mercury cells probably accounts for the popularity of the mercury cell process in these remote locations. The absence of salt in the caustic, which was at one time the major advantage of mercury cell technology, does not apply in this case nor for that matter, in any but a very few other chemical processes. (The production of rayon, once the major user, is no longer an important factor.)

TABLE 23. – United States Chlor-Alkali Manufacturers and Estimated Mercury Losses of Plants, by State, 1973

Region and State	Company	Annual Estimated Chlorine Prod. (thousands of tons)	Estimated Mercury Losses to the Environment (kg)			
			Land[a]	Air	Water	Total
Atlantic						
Delaware	Diamond	133	8,385	827	235	9,447
Georgia	Olin	93	5,776	827	150	6,753
	Allied	63	5,611	827	90	6,528
Maine	Sobin	71	3,778	827	115	4,720
New Jersey	Linden	154	15,059	827	280	16,166
New York	Hooker	56	5,171	827	80	6,078
	Olin	56	5,171	827	80	6,078
	Allied	56	6,895	827	80	7,802
North Carolina	Allied	56	3,867	827	80	4,774
West Virginia	Allied	176	20,441	827	325	21,593
	PPG	56	5,110	827	80	6,017
Subtotals		970	85,264	9,097	1,595	95,956
North Central						
Illinois	Monsanto	84	5,990	827	130	6,947
Kentucky	Goodrich	100	8,674	827	170	9,671
	Pennwalt	104	9,021	827	175	10,023
Ohio	Sobin	33	2,120	827	50	2,997
Tennessee	Olin	124	16,004	827	220	17,051
Wisconsin	BASF	57	2,966	827	80	3,873
Subtotals		502	44,775	4,962	825	50,562
South						
Alabama	Stauffer	116	7,897	827	200	8,924
	Olin	70	8,017	827	110	8,954
	Diamond	70	4,523	827	110	5,460
	Diamond	71	8,137	827	115	9,079
Louisiana	PPG	218	17,838	827	415	19,080
	Stauffer	167	12,538	827	310	13,675
	BASF	48	5,240	827	55	6,122
Texas	Diamond	56	7,621	827	80	8,528
	Al. Co. of Am.	157	13,910	827	285	15,022
Subtotals		973	85,721	7,443	1,680	94,844
West						
Washington	Georgia-Pac.	45	3,624	827	55	4,506
	Weyerhaeuser	88	7,671	827	140	8,638
Subtotals		133	11,295	1,654	195	13,144
U.S. Total	28 Plants	2,578	227,055	23,156	4,295	254,506

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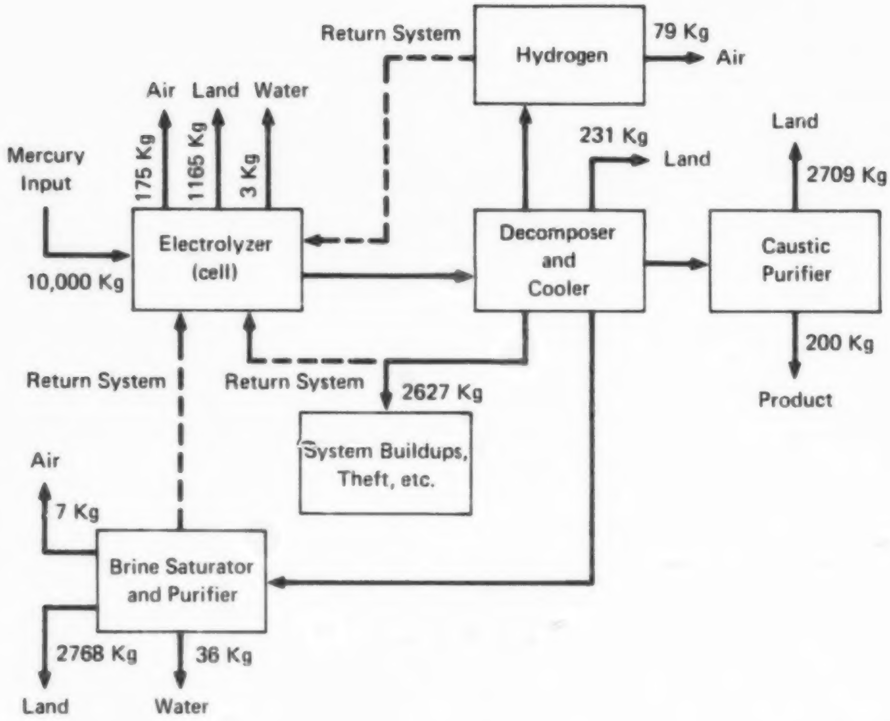
a. Land losses included in this table are sludge only and do not include other mercury waste materials such as filter cake, anode graphite, etc.

Source: URS Research Company; Ref. 60, 62, 63.

manufacturers are the DeNora (13 plants), Olin (6 plants), Solvay (4 plants), and Uhde (5 plants) (see Ref. 63).

1973 Technology. Figure 29 is a flow diagram of a "typical" chlorine and caustic soda plant which manufactures 500 tons of chlorine gas and 570 tons of caustic per day. The basic unit in the plant is the mercury cell, which theoretically recirculates the same mercury continuously. However, mercury losses do occur from this cell, and makeup mercury must be added occasionally. The Uhde cell, which may contain 2,651 kg of mercury, is typically 2.0 meters by 17.6 meters and is constructed of heavy gage steel to which hard rubber-covered channels are bolted to form the sides. The bottom has a slight slope (4 to 5 millimeters/meter) so that mercury, which is introduced at the top of the cell through an end box seal, flows uniformly down the flat bottom of the cell to a depth of about 0.003 meter and is removed (with an amalgam content of less than 0.5 percent sodium) through an outlet end box. Together with the mercury, purified brine is introduced at the top of the cell, covering the flowing mercury to a depth ranging from less than 0.03 meter at the top of the cell to almost 0.12 meter at the bottom of the cell. Multiple anodes extend down from the cell cover (which may be attached to the body of the cell with a flexible gasket or with a firm connection). A high-density, low-voltage current (less than 0.5 amp/cm^2), which is carried by massive bus bars from cell to cell in series connection, activates these anodes. The anodes then electrolyze the brine to form chlorine, which is collected at the top of the cell or at slots in the anode. The sodium amalgam is deposited in the moving mercury cathode. After leaving the end box, this amalgam enters a decomposer (also called a denuder) which is typically affixed to the end of the cell.

The decomposer is a small reactor that is normally packed with pieces of graphite which, in the presence of trickling water, cause the sodium amalgam to decompose, forming 40- to 60- percent caustic and releasing the mercury for return to the inlet of the cell. Hydrogen is also formed (99.9 percent pure). Its temperature of over 80°C allows mercury vapor to be incorporated in the gas. To minimize losses, the hydrogen is cooled at the decomposer to about 55°C; this removes over 98 percent of the mercury, which is then returned to the cell. The remainder of the hydrogen stream is further purified so that


Return System
Hydrogen
79 Kg
Air
Air
Land
Water
175 Kg
1165 Kg
3 Kg
Mercury Input
10,000 Kg
Electrolyzer (cell)
231 Kg
Land
Land
2709 Kg
Decomposer and Cooler
Caustic Purifier
200 Kg
Product
Return System
Return System
2627 Kg
System Buildups, Theft, etc.
Air
7 Kg
Brine Saturator and Purifier
2768 Kg
36 Kg
Land
Water

SOURCE: URS Research Company.

Figure 29 MERCURY LOSSES FROM A TYPICAL CHLOR-ALKALI MANUFACTURING PLANT, 1973

99 percent or more of the mercury is ultimately removed. The gas is then normally flared.

The brine which leaves the cell is depleted of its sodium chloride content and it carries some mercury with it. This depleted brine is returned to the brine saturator and is treated to remove undesirable chemicals (primarily calcium and magnesium salts) which are introduced in that operation. This purification step results in the formation of sludges which incorporate significant quantities of mercury. These sludges must be segregated for further treatment and disposal. The purified and saturated brine is recycled to the cell.

A materials balance for mercury in a "typical" chlor-alkali plant is shown in Table 24. With the 1973 technology, mercury consumption is assumed to be 0.4 pound of mercury per ton of chlorine produced, or 31,780 kg per year for the 500 tons/day plant. Table 24 shows the environmental mercury losses of the "typical" plant by source and form of emission.

In this materials balance certain assumptions have been made to account for all mercury losses. For example, a buildup of the mercury "inventory" within each cell occurs over time as a result of changing operating conditions; these may include the formation of a mercury "butter" which effectively reduces the mercury available for reaction temporarily, or the need to operate at higher current densities to increase production, which requires a higher mercury level, etc. Mercury also accumulates in piping and other equipment and is an apparent loss. Other poorly defined losses, for example theft, can occur. We have made estimates to cover all known or suspected losses so that the amount of mercury introduced (i.e., 0.4 lb per ton of chlorine produced) is accounted for. Actually, such accounting is not possible in a typical mercury cell chlor-alkali plant. Instead, for the industry as a whole, only about 50 percent of its annual mercury consumption can be accounted for. This does not imply that mercury is indiscriminately lost to the environment; rather, it is most difficult to estimate where mercury may accumulate in the system and to what extent. For example, we estimate that each year, in this typical plant, 523 kg of mercury enter structural members and can only be recovered when the plant is disassembled after its active lifetime. The industry is concerned with this lack of accountability and is continuing to seek better results. Many plants now run radioactive inventories of the mercury content of each cell at least

TABLE 24. - Materials Balance for Chlor-Alkali Plant (500 tons of chlorine per day) with a Mercury Efficiency of 0.40 Pound per Ton Chlorine, 1973 (kilograms)

	Plant Losses						Plant Inventory	
				Other Losses				
	Air Losses	Water Losses	Land Losses	Product	Theft	HLW[a]	System Buildups	Escapage
Mercury Remaining in Process Loop								
Cell							(265,227) 8,859	
Stored Inventory							(9,171) 0	
Uncontrolled Traps							(227) 65	
Equipment Holdups								
. Gases							(2,724) 783	
. Liquids							(1,362) 392	
Within the Brine							(136) 0	
Mercury Consumed during Manufacture								
Product								
. Caustic Soda & Sodium Hypochlorate				636				
. Chlorine				1				
Air								
. End Boxes }								
. Hydrogen & Waste Air }	350							
. Cell Room	455							
Water		276						
Solids								
. Sludges			14,695					
. Filter Cake			61					
. Anode & Decomposer Graphite			895					
. Misc. Solids			3,541					
Other								
. Recycling System	22							
. Mercury Flask								42
. Theft					184			
Long-Term Structural								(5,312) 523
Subtotal (kg) (percent)	827 (2.6)	276 (0.9)	19,192 (60.3)	637 (2.0)	184 (0.6)		10,099 (31.8)	565 (1.8)
Total (31,780 kg) (percent)	21,116 (66.4)						10,664 (33.6)	

Source: URS Research Company

a. High-Level Waste

Note: Numbers in parentheses indicate total mercury in system in previous years. The number below is the amount of mercury added during the study year. For example, the cell contained 265,227 kg in 1972 and 271,586 kg in 1973.

once a year, but this expensive technique is only accurate to about ±1 percent.

Losses to air from a typical chlor-alkali plant occur chiefly at the end box, the electrolyzer cell, from hydrogen and waste air flaring, and from the brine recycling system. Except for the brine recycling system, air losses are assumed to be within EPA requirements of 2,300 grams per day (Ref. 64). The small recycling system losses, however, occur at a variety of uncontrolled locations within the plant (brine purifier and saturator, leaks at fittings and seals, and settling ponds).

As a part of good housekeeping practice, the inevitable mercury leaks which occur under the cell house are regularly collected, by hosing with water, into sumps. The collected mercury is returned to the system and the mercury-containing water is sent to the water purification plant where it is joined by the supernatant liquid from the sludge settling pond. The collected waters are usually treated with sodium sulfide, forming the very insoluble mercuric sulfide which is easily removed by filtration prior to discharge to a local receiving water body.

The amount of mercury that can be discharged to the aquatic environment depends on the type and size of the water body. Proposed EPA regulations limit the maximum mercury discharge to 0.735 kg/day for streams, 0.612 kg/day for lakes, 12.2 kg/day for estuaries, and 14.7 kg/day for coastal waters (Ref. 65). The mercury discharge for the typical plant was conservatively assumed to be 0.79 kg/day (276 kg per year).

Mercury losses to land are the most significant waste problem for chlor-alkali plants. Most of this waste is discharged in sludge (approximately 200 ppm of mercury) generated by the brine and caustic purifiers. The sludge is concentrated in settling ponds and deposited in local industrial landfills. Other solids with higher mercury levels include spent graphite (anodes and decomposer), filter cakes (sludge and water treatment residues), and miscellaneous solids (discarded wood and plastic cell room flooring, machinery, pipes, fittings, etc.). These solids may be incorporated in the sludge or shipped to high level industrial disposal sites.

Chlorine gas contains, at most, trace amounts of mercury (assumed to be 0.005 ppm). However, caustic, even after treatment, contains approximately

3.7 ppm of mercury. Most of this caustic is shipped out of the plant to other manufacturers and is consumed in their products.

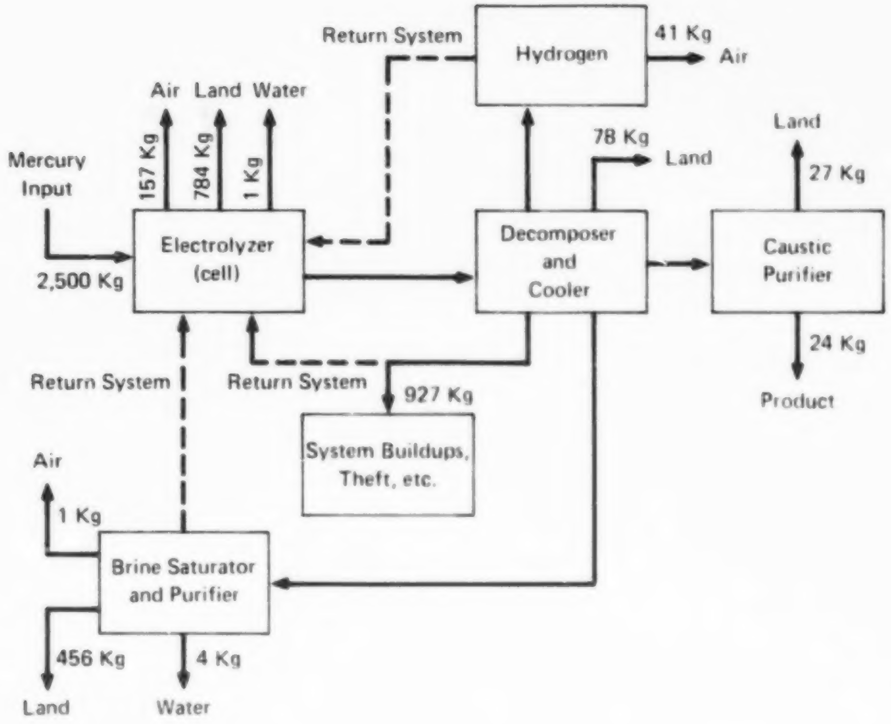
Theft of mercury from traps, flasks, sumps, and other sources is a problem at most chlor-alkali plants. It is believed that most of this mercury is sold to local salvage firms for resale. Complete elimination of this problem is impossible because of the quantity used at the plants and the accessibility of mercury.

The system buildups shown in Table 24 indicate the amount of mercury known to be in the system the previous year (number in parenthesis) and the unknown amount of mercury trapped within or added to that system. For example, uncollected traps contain 227 kg of mercury on inventory day, but an additional 65 kg are in "miscellaneous" and "other" traps or adhere to equipment. The system buildup is not an environmental mercury loss.

Small amounts of mercury will remain in empty mercury flasks, because they are discarded rather than recycled. We estimated this loss at approximately 0.0454 kg per flask (3 to 4 drops). The other loss in this category, long-term structural, occurs as mercury vapor or metal is absorbed into a building's superstructure. This loss remains within the plant until the structure is discarded.

1983 Technology. Figure 30 is a flow diagram for the technology which will probably be used in 1983 by the "typical" chlor-alkali plant (500 tons of chlorine per day). Table 25 is a materials balance for this facility. Mercury consumption in chlor-alkali plants by 1983 is estimated to be reduced to 0.10 lb of mercury per ton of chlorine produced, for a total of 7,945 kg per year. This reduction is expected to be brought about by the industry's efforts to control mercury emissions to conform with federal, state, and local regulations. Individual plants are expected to have almost complete accountability of their mercury consumption, which will enable them to control internal plant discharges. Also, technological changes by 1983 are expected to help chlor-alkali plants in the recovery and final disposition of mercury waste.

Mercury losses to air may be reduced 40 percent, or to 492 kg, for the typical plant by 1983. Most of this reduction will occur at the end boxes and hydrogen streams when the waste gases are chilled, demisted, and put through


Return System
Hydrogen
41 Kg
Air
Air Land Water
157 Kg
784 Kg
1 Kg
Mercury Input
2,500 Kg
Electrolyzer (cell)
78 Kg
Land
Land
27 Kg
Decomposer and Cooler
Caustic Purifier
24 Kg
Product
Return System
Return System
927 Kg
System Buildups, Theft, etc.
Air
1 Kg
Brine Saturator and Purifier
456 Kg
4 Kg
Land
Water

SOURCE: URS Research Company

Figure 30 MERCURY LOSSES FROM A TYPICAL CHLOR-ALKALI MANUFACTURING PLANT, 1983

TABLE 25. - Materials Balance for Chlor-Alkali Plant (500 tons of chlorine per day) with a Mercury Efficiency of 0.1 Pound Per Ton of Chlorine, 1983 (kilograms)

	Plant Losses (kg)						Plant Inventory (kg)	
	Air Losses	Water Losses	Land Losses	Other Losses			System Buildups	Escapage
				Product	Theft	HLW[a]		
Mercury Remaining in Process Loop								
Cell							(265,227) 2,703	
Stored Inventory							(4,585) 0	
Uncontrolled Traps							(272) 13	
Equipment Holdups								
. Gas							(2,724) 156	
. Liquids							(1,362) 79	
Within the Brine							(136) 0	
Mercury Consumed during Manufacture								
Product								
. Caustic Soda & Sodium Hypochlorate				75				
. Chlorine				1				
Air								
. End Box . Hydrogen & Waste Air	35							
. Cell Room	455							
Water		16						
Solids								
. Sludges			403			a		
. Filter Cake			61			a		
. Anode & Decomposer Graphite			249			a		
. Misc. Solids			3,541			a		
Other								
. Recycling System	2							
. Mercury Flask								10
. Theft					19			
Long-Term Structural								(1,326) 127
Subtotal (Percent)	492 (6.2)	16 (0.2)	4,254 (53.6)	76 (1.0)	19 (0.2)		2,951 (37.1)	137 (1.7)
Total (7,945 kg)	4,857 (61.2)						3,088 (38.8)	

Source: URS Research Company

a. HLW (High-Level Waste) - Some or all of the final wastes which are greater than 400 ppm and cannot be further treated are sent to controlled disposal sites or scavengers.

Note: Numbers in parentheses indicate total mercury in system in previous years. The number below is the amount of mercury added during the study year. For example, the cell contained 265,277 kg in 1982 but 267,930 kg in 1983.

microsieve filters. Also, with tighter internal plant controls on mercury consumption, losses in the recycling system will be reduced.

Losses to water will be reduced substantially because of waste water purification technology advances. This advancement will be brought about by government regulations requiring industries to meet best practical waste treatment standards by 1977 and best available waste treatment standards by 1983. Therefore, the mercury discharge for the typical plant should be approximately 0.05 kg/day, or 16 kg per year.

The major changes in the 1983 technology occur in pollution control technology associated with the treatment of sludges. Two attractive processes are now under development for recovery of mercury from sludges. One, developed and patented by Georgia-Pacific, involves retorting the sludge with condensation of the released mercury. The other, which is reported in the literature, involves the dissolution of the mercury in the sludge in a solution of sodium hypochlorite, with possible further purification steps and subsequent return to the system. It is forecast that some high level wastes will continue to be generated: these will continue to be segregated in special industrial repositories. It is expected that sludge treatment will reduce the mercury entering the environment to 403 kg in 1983 for the typical plant.

Other significant land loss reductions (Table 25) will occur in decomposer graphite emissions. (Anode losses are expected to be eliminated by 1983 as the industry completes the switch from the graphite anode to the dimensionally stable anode.) Also, reductions in decomposer graphite discharges to the environment are likely to result from adoption of good housekeeping practices such as treating the waste graphite with hypochlorite solution.

Mercury losses to product (almost entirely caustic soda) will decrease significantly. This reduction will take place at the caustic purifier where the mercury enters the sludge system for treatment. Technological changes are expected to reduce the residual mercury content of caustic alkali to 0.4 ppm by 1983.

Losses due to theft, systems buildups, and miscellaneous escapage will decrease by 1983 because more attention will be concentrated on locating these sources and eliminating them. Also, leaks will be fixed promptly, traps will be collected regularly, and plant structures will be sealed properly. Generally, the attitude will change from moderate concern to major concern with controlling internal plant mercury consumption.

Estimated mercury losses from a typical chlor-alkali plant's operation in 1973 and 1983 are compared in Table 26. The 1983 technology values are based on a mercury consumption rate of 0.1 lb per ton of chlorine produced and no expansion or decrease in mercury cell chlorine production. Mercury loss to the environment is expected to decrease by 78 percent during the decade.

Alternative Technologies. Chlorine and caustic alkali cannot be economically or practically eliminated from the U.S. inorganic chemical industry. However, two alternatives could be implemented in the future to eliminate or reduce mercury pollution. (The economic impact of these two alternatives will be dealt with at some length in the next section.)

The first alternative is to switch from the mercury cell process to another process. The diaphragm cell process is the most attractive, because it is the major chlorine process used in the United States (accounting for 69 percent of chlorine production in 1973). Other processes generate chlorine as a by-product (7 percent of 1973 chlorine production).* Like the mercury process, the diaphragm process generates hazardous wastes--most significantly asbestos, lead, and chlorinated hydrocarbons. Asbestos waste, however, is expected to be largely eliminated by 1983 as plastic membranes are developed to replace asbestos. Continuing development of improved diaphragm cells, accelerated by the current disfavor of mercury cells, is likely to result in even higher efficiencies and lower discharges of noxious or hazardous substances, further enhancing the competitive position of diaphragm cells. However, complete replacement of existing mercury cell facilities within a 10-year period is most unlikely.

The second alternative--and the more practical--is to regulate the discharges to air, water, land, and product. By 1983 mercury pollution control

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* The most significant of these processes is the Downs' cell (electrolysis of molten sodium chloride to obtain sodium as the principal product and chlorine as the minor product).

TABLE 26. - Estimated Mercury Losses from Typical Chlor-Alkali Plant Operations, 1973 and 1983
(kilograms)

Mercury Losses to	1973	1983
Air	15,869	12,527
Water	1,951	113
Land	244,875	48,310
Product	8,661	1,035
Totals	271,356	61,983

Source: URS Research Company

technology is likely to be well developed, and, as indicated by Table 26, environmental mercury losses should be reduced to acceptable limits. A significant reduction in mercury consumption by 1983 is likely; several plants already have consumption rates approaching 0.1 lb of mercury per ton of chlorine.

Manufacture of Mercurials

The manufacture of mercury compounds (mercurials) accounted for almost 20 percent of total U.S. consumption of mercury in 1973. Some 10,718 flasks were consumed in making organic and inorganic mercurials in the following Bureau of Mines usage categories: agricultural, 17.1 percent; catalyst, 6.3 percent; paint, 70.9 percent; and pharmaceuticals, 5.7 percent. Mercurials for any or all of these categories are often manufactured in a single facility. Hence, in this section we consider the manufacture of inorganic and organic mercurials as a single technology, but one with broad applications.

The manufacture of mercury compounds can be assigned to several SIC groups (for example, 2818 organics; 2819 inorganics; 2833 medicinals). The process initially involves conversion of the metal into one of several inorganic mercurials which in turn is used to produce other inorganic, or a variety of organic, mercurials. There are only about 16 manufacturers of mercury compounds in the country, and often the same facility manufactures both inorganic and organic compounds.

Mercury compounds, although essential in a variety of uses, are a very low-volume chemical for which statistical data are virtually unobtainable. However, we have made an estimate, based on available information, that the total value of shipments for all mercury compounds (including both intermediates and final product) was about $30 million in 1973 and required about 500 production workers. In contrast, the relatively small inorganic pigments industry (SIC 2816) employed 8,900 production workers in 1967, with a total value of shipments of over $500 million.* Despite their low volume, some 45 mercury compounds are regularly manufactured in the United States, according to the Directory of Chemical

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* The production of mercury compounds is not an industry per se. In most cases the production of mercurials is almost a sideline--to a much larger chemical facility. Even in facilities that specialize in mercurials, the production of nonmercurials is usually an important consideration.

Producers (Ref. 88). Of these, however, only four (mercuric chloride, red and yellow mercuric oxide, mercurous chloride, and ammoniated mercury) are of sufficient commercial interest to merit a listing in the Chemical Marketing Reporter.

The price of mercury compounds is quite dependent upon the selling price of mercury metal (although a time lag between changes in the price of the metal and of the compound can be observed); as a rule of thumb, inorganic mercurials sell for one and a half to two times the billing price for mercury metal, whereas organic compounds sell for three and a half to four times the cost of the metal. The higher price for the organics is primarily attributable to their usage of intermediate inorganics and of more complicated syntheses. For example, the quoted price of mercuric chloride (with a 73.9 percent mercury content) varied between \$7.17 and \$8.66 per pound in July 1975, whereas the price for phenylmercuric acetate (with a 59.6 percent mercury content) is estimated to be \$14 per pound.

Because the mercurials are mature chemicals with a long history of manufacture and because, in most cases, their production is a simple process, manufacturing facilities are generally simple and use standard technology. These facilities tend to be small--for example, a 1,000-gallon reactor is considered average for the industry; the adoption of small batch processes was dictated by the high cost of the materials (primarily of mercury) and the instability of the market. For reasons which are not completely clear, the major manufacturing center for mercury compounds lies within a rather small region in New Jersey which accounts for almost 90 percent of all mercurials made in the nation.

Catalysts represent a small, but important, secondary manufacturing usage of mercury compounds. Mercury catalysts are still used to a small extent in the synthesis of vinyl chloride (from acetylene and hydrogen chloride) and in the synthesis of vat dyes. These secondary manufacturing usages are described briefly in the following subsections.

Production Sites. The 16 U.S. mercurials manufacturing plants and their estimated production in terms of use category are listed in Table 27. As mentioned above, these production sites are highly concentrated in the New Jersey industrial region, which, except for pharmaceutical end uses, accounts

TABLE 27. - Estimated Mercury Consumption of Mercurials in 1973, by Plant and Product End Use Category[a]
(kilograms of Hg consumed)

Plant	Location State	 City	Catalysts	Agriculture	Paint	Pharmaceuticals	Total
Tenneco	California	Long Beach	1,378	3,447	17,234	-	22,059
Eli Lilly	Indiana	Indianapolis	-	1,723	-	2,964	4,687
Becton, Dickinson	Maryland	Baltimore	-	-	-	4,136	4,136
Strem	Massachusetts	Danvers	-	1,723	-	-	1,723
Mallinckrodt	Missouri	St. Louis	-	5,170	-	3,447	8,617
City Chemical	New Jersey	Jersey City	3,447	3,447	-	-	6,894
W. A. Cleary	New Jersey	Somerset	-	10,340	20,680	-	31,020
Cosan	New Jersey	Clifton	-	-	79,274	-	79,274
Mallinckrodt	New Jersey	Jersey City	1,723	4,137	-	5,170	11,030
Merck	New Jersey	Hawthorne	3,447	8,961	6,893	5,170	24,471
Richardson-Merrill	New Jersey	Phillipsburg	1,723	-	-	-	1,723
Tenneco	New Jersey	Garfield	3,447	8,617	68,934	-	80,998
Troy	New Jersey	Newark	3,447	10,340	41,464	-	55,251
Ventron	New Jersey	Woodridge	3,447	5,170	27,574	-	36,191
RSA-Ardsley	New York	Ardsley	345	-	-	-	345
Pennwalt	Oklahoma	Tulsa	999	-	-	-	999
Totals			23,403	63,075	262,053	20,887	369,418

[a] Values are based on estimated usage, in flasks, and were rounded to the nearest kg.

Source: URS Research Company

for about 88 percent of total mercurials production. (The known concentration of these producers in New Jersey was one reason for selecting that state as part of a study region; however, as discussed earlier in connection with the inventory results, the combined impact of these numerous producers was found not to be significant for that region.) More quantitative data on the technology involved, by-products produced, etc., are not available and would in any case have little meaning, since these statistics can readily change as markets change for specific compounds.

Mercury compounds are used as catalysts in two major types of chemical syntheses--the manufacture of vinylchloride monomer (VCM) and that of anthroquinone "vat" dyes. (Mercury catalysts are also used in foaming polyurethane plastics in place and in other minor applications related to urethane. However, the use of mercurials in these operations is small when compared to the whole industry, and the manufacturing plants are widely dispersed around the nation; therefore, a use-site tabulation has not been attempted for them.) The few production sites for the two principal uses of mercury catalysts are shown in the tabulations below. These rough estimates indicate again that New Jersey is an important manufacturing center (for vat dyes), but that the production of VCM is limited to the Southeast petrochemical complex. In both cases production involving mercury as a catalyst is small in comparison with the manufacture of other mercurials.

Use Sites for Production of Vat Dyes

State	Company	Estimated Use of Mercury in 1973 (kg)
New Jersey	American Cyanamid	270
	G.A.F. Corporation	270
	Otto B. May Company	270
	Mobay Chemical	270
	Toms River Chemical (Ciba-Geigy)	270
Pennsylvania	American Color & Chemical	250
Massachusetts	Nyanza, Inc.	240
North Carolina	Soll-Tex Chemical	230
Total		2,070

Use Sites for Production of Catalysts for Vinyl Chloride Monomer

State (City)	Company	1973 Production of VCM (millions of kg)	Estimated Use of Mercury in 1973 (kg)
Louisiana (Geismar)	Monochem	136	9,800
Texas (Houston)	Tenneco	102	7,400
Total		238	17,200

1973 Technology. Although mercury compounds have been synthesized since time immemorial, the quantities involved are small and the general interest level in commercial processes is likewise small. Therefore the literature essentially ignores commercial processes for the production of mercurials. But at the same time, manufacturers are reluctant to release details concerning their processes, possibly because of this very dearth of information. However, based upon an analysis of similar inorganic reactions and on the information that could be extracted from the available literature,* we have concluded that the inorganic and organic syntheses involved are straightforward and require only simple equipment such as corrosion-resistant atmospheric reactors, column stills, and so on. We therefore felt that consideration of a few commercial processes for which details are known should suffice to typify the industry as a whole.

The main concern in this portion of the study was to determine the emissions to air, water, and land from the various processes used in making mercurials. Accordingly, we selected four inorganic processes and one organic process for consideration. The inorganics selected are among those most commonly used, and they provide intermediates for production of organic mercurials.

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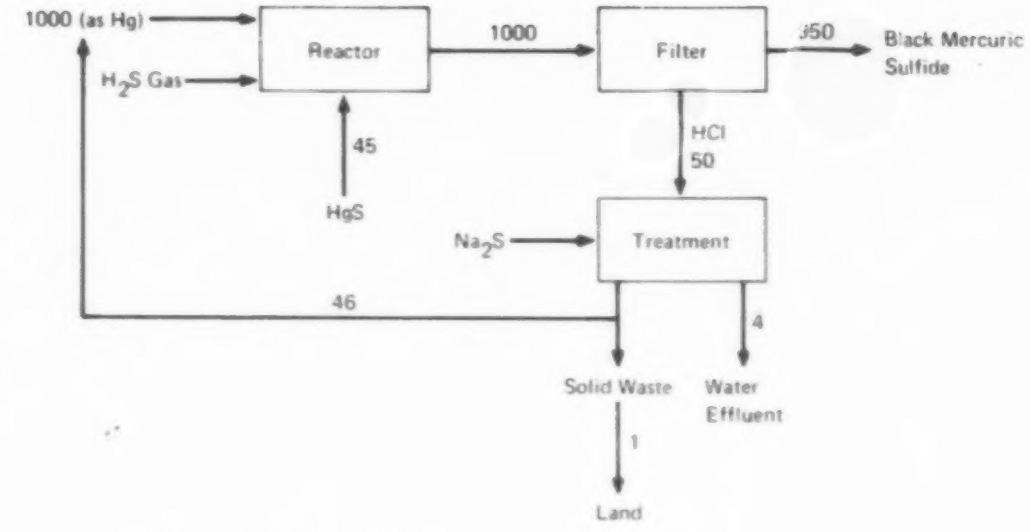
* Ref. 68, which is one of our basic sources of information, provides additional flow charts for alternate ways of producing mercuric sulfide, mercuric chloride, and red mercuric oxide. It also includes flow charts for the manufacture of yellow mercuric oxide and mercurous chloride.

Figure 31a is a flow diagram of a common production method for black mercuric sulfide which utilizes an aqueous phase reaction. In this and subsequent diagrams we have assumed yields of between 95 percent and 98 percent, although some sources claim even higher yields. We then assigned mercury losses to air, water, or land, depending on the type of reaction. As can be seen in Figure 31a (a typical case) most of the loss is recaptured in the treatment process where the mercury wastes are precipitated by sodium sulfide treatment, removed by filtration, and then recycled (after further purification) back into the process. Losses to water from the treated aqueous wastes are low, and losses to air are minimal.

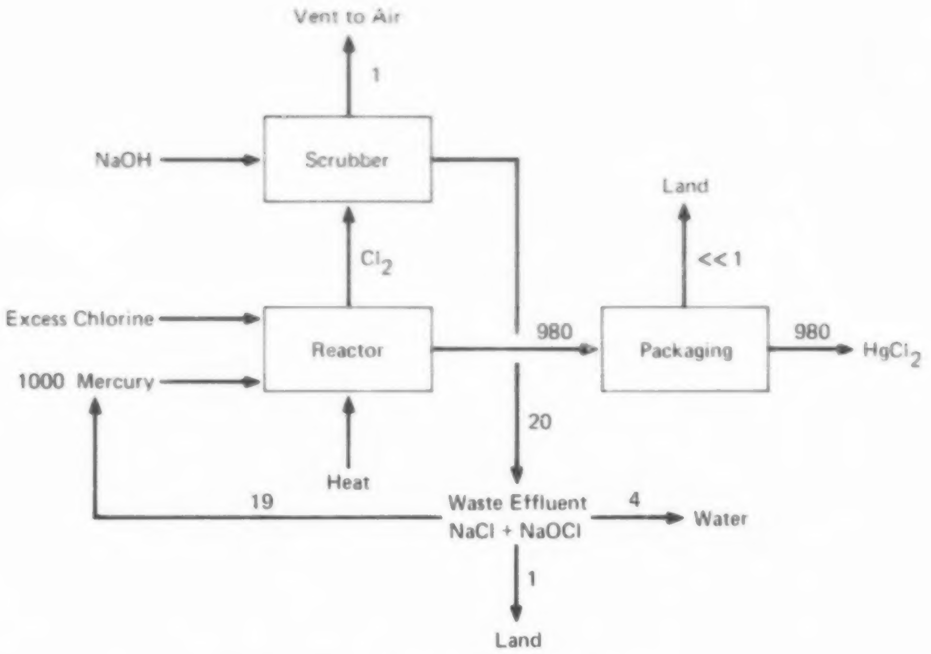
Figure 31b shows a common production method for mercuric chloride (known as corrosive sublimate) in which mercury metal is reacted in a closed, glass-lined or stainless steel vessel with an excess of chlorine. Heat is applied to promote a gas phase reaction which results in high yields of the mercuric chloride. Unreacted mercury and chlorine are trapped in a caustic scrubber and this waste effluent is treated to recover small amounts of mercury (as mercuric sulfide).

Figure 32 shows two alternate, and common, methods for producing red mercuric oxide (widely used in battery manufacture and as an intermediate in the synthesis of other mercurials). Both of these aqueous phase reactions produce high yields, and waste effluents are treated to recover most of the mercury losses.

Figure 33 is a flow diagram of the manufacture of the most widely used organic mercurial--phenylmercuric acetate. Here again yields are high and mercury losses are small, and most of the mercury that is lost is recycled from the waste effluent. (It should be noted that the very high value of the waste mercury is in itself an incentive to recover it; in this case the recovered mercury represents a savings of over 2 percent on raw material costs alone. In contrast, in the chlor-alkali industry the amounts of mercury losses are much larger, but the additional cost per kilogram of product produced is insignificant.) The finished phenylmercuric acetate is sold either as a dry powder (100 percent) or as a dilute suspension.


1000 (as Hg)
H_2S Gas
Reactor
1000
Filter
950
Black Mercuric Sulfide
45
HgS
HCl
50
Na_2S
Treatment
46
4
Solid Waste
Water Effluent
1
Land

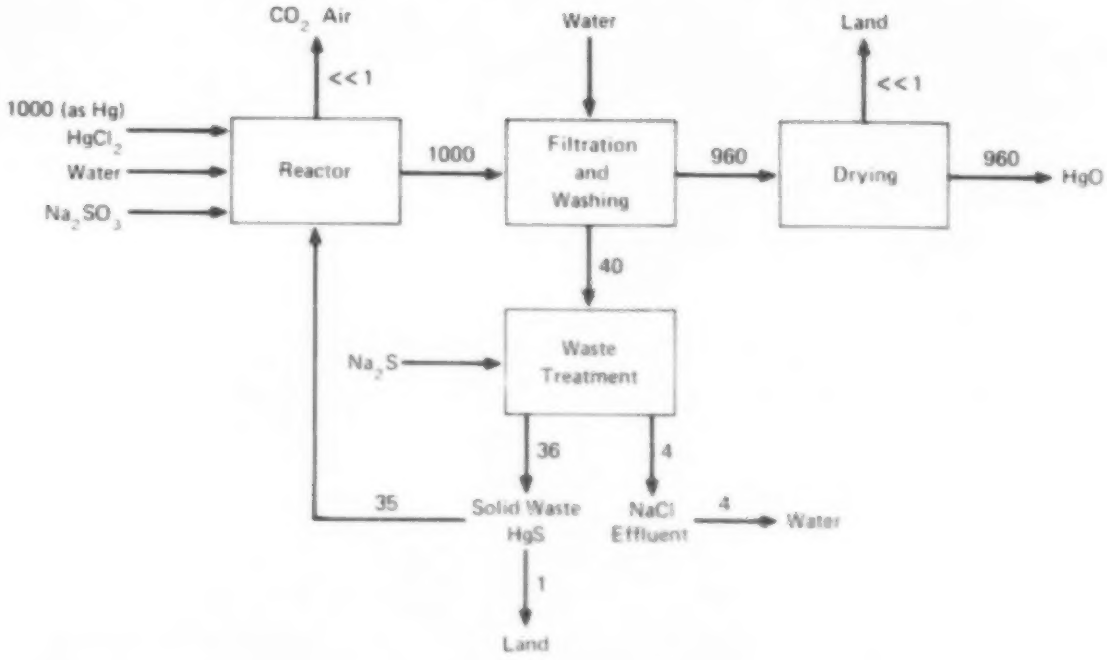
(a) MERCURIC SULFIDE


Vent to Air
1
NaOH
Scrubber
Cl_2
Land
<<1
Excess Chlorine
Reactor
1000 Mercury
980
Packaging
980
$HgCl_2$
20
Heat
19
Waste Effluent
NaCl + NaOCl
4
Water
1
Land

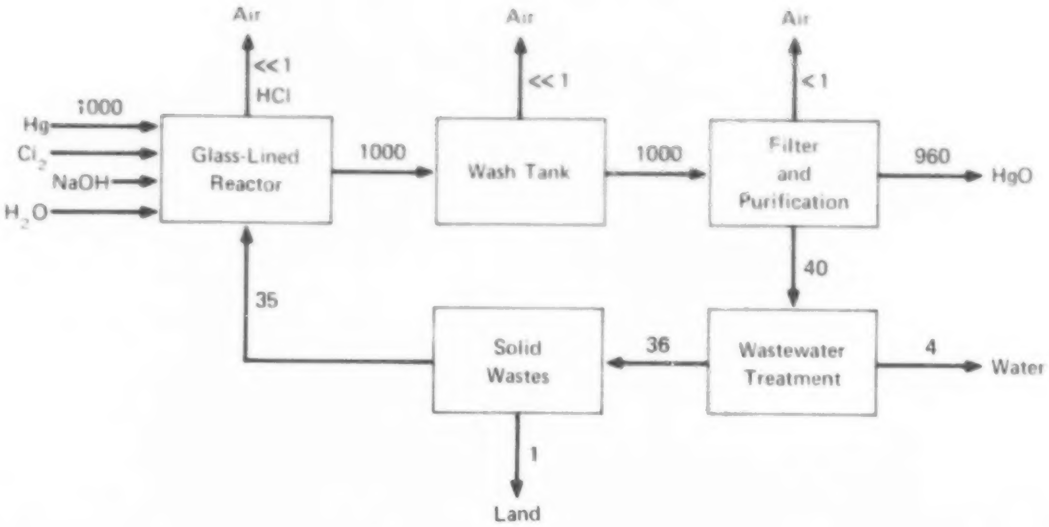
(b) MERCURIC CHLORIDE

SOURCE: Ref. 60.

Figure 31 MERCURY BALANCE FOR THE PREPARATION OF MERCURIC SULFIDE AND MERCURIC CHLORIDE


CO2 Air
<<1
Water
Land
<<1
1000 (as Hg)
HgCl2
Water
Na2SO3
Reactor
1000
Filtration and Washing
960
Drying
960
HgO
40
Na2S
Waste Treatment
36
4
35
Solid Waste HgS
NaCl Effluent
4
Water
1
Land

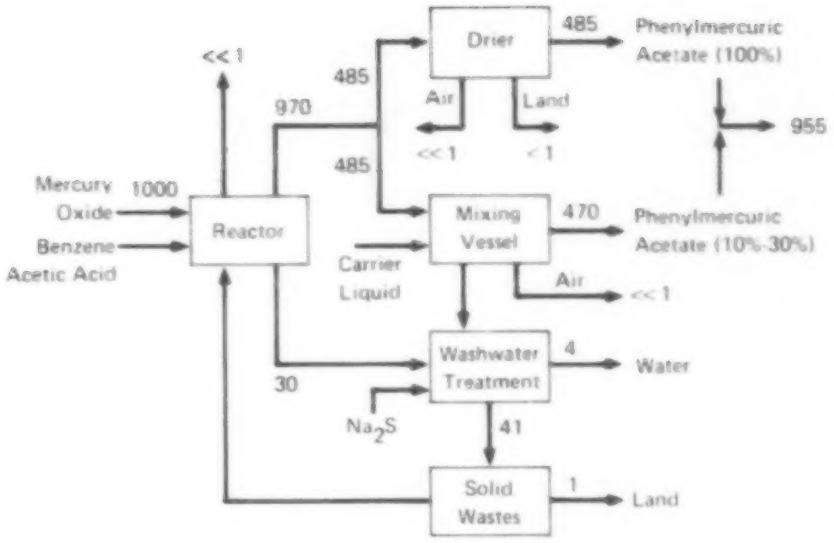
(a) FROM MERCURIC CHLORIDE


Air
<<1
HCl
Air
<<1
Air
<1
1000
Hg
Cl2
NaOH
H2O
Glass-Lined Reactor
1000
Wash Tank
1000
Filter and Purification
960
HgO
40
35
Solid Wastes
36
Wastewater Treatment
4
Water
1
Land

(b) FROM MERCURY METAL

SOURCE: Ref. 60; URS Research Company.

Figure 32 MERCURY BALANCE FOR TWO METHODS FOR PRODUCTION OF RED MERCURIC OXIDE


Drier
485
Phenylmercuric Acetate (100%)
<< 1
485
970
Air
Land
<< 1
< 1
955
485
Mercury Oxide
1000
Benzene Acetic Acid
Reactor
Mixing Vessel
470
Phenylmercuric Acetate (10%-30%)
Carrier Liquid
Air
<< 1
Washwater Treatment
4
Water
30
Na_2S
41
Solid Wastes
1
Land

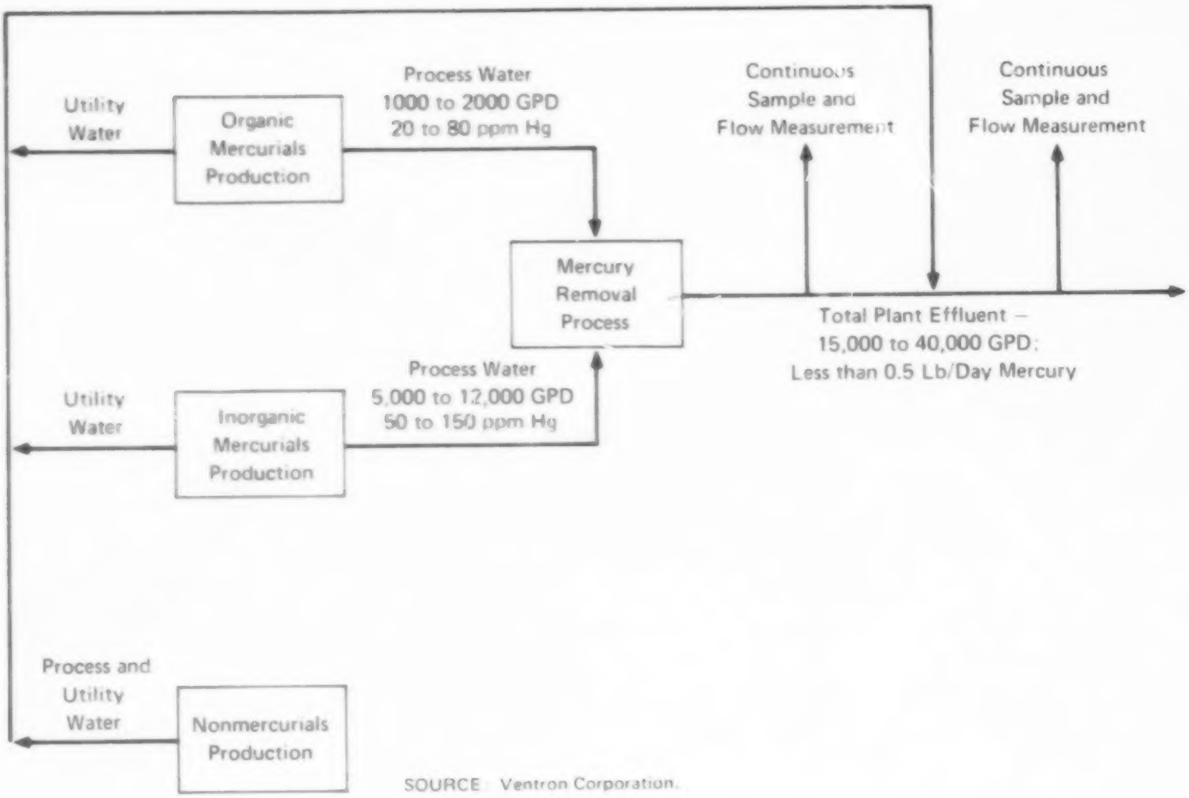
SOURCE: URS Research Company.

Figure 33 MERCURY BALANCE FOR SYNTHESIS OF PHENYLMERCURIC ACETATE (using 1973 technology)

In general, mercurials are manufactured in small reaction vessels, producing a slurry in an inert liquid which can conveniently be filtered to recover the desired product (which may be further purified); after treatment, the filtrate is discharged. In the 1973 technology, the filtrate, which may contain unreacted mercury compounds, is treated with sodium sulfide to precipitate mercuric sulfide and, after a second filtration, is discharged to the sewer. Because these effluent flow rates are so small and the removal rate for residual mercury is so high, the total quantities of mercury discharged are low. Figure 34, which was supplied by the Ventron Corporation, shows the control capability currently in use by this major manufacturer of mercury compounds which results in a final effluent containing less than 0.23 kg of mercury per day. We estimate that, on the average, about 0.4 percent of the total mercury used in a given plant will be lost to the environment, primarily to water.

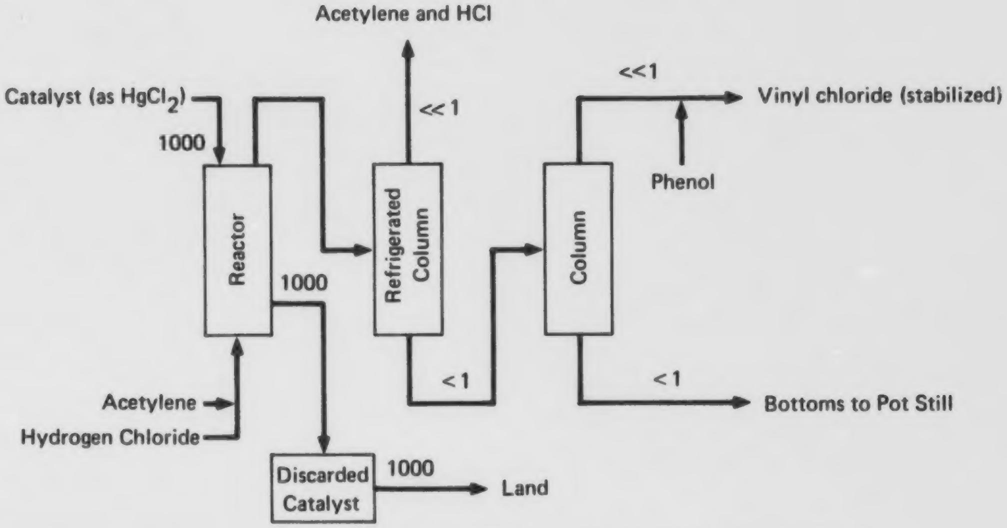
As mentioned earlier, vinyl chloride monomer (VCM) was still being produced in 1973 from acetylene and hydrogen chloride, using a mercuric chloride catalyst. Figure 35 is the flow diagram for this reaction, and indicates the resultant mercury losses to the environment. It is believed that most of the mercury losses occur when the carbon pellets impregnated with mercuric chloride are discarded but, as indicated on the figure, other small losses to product and to air can occur. However, the overall loss is of the same order as that for other chemical reactions involving mercury--less than one-half of 1 percent of throughput. It seems likely that the losses for synthesis of the anthroquinone dyes would be of the same order, although this belief cannot be verified because of lack of knowledge concerning the processes actually employed.

Both of these uses of mercury as a catalyst are on the decline. According to available information, the Tenneco plant in Texas has changed its production route for vinyl chloride monomer and stopped using mercurial catalyst in 1974. Usage of anthroquinone, which is sulfonated in the presence of mercuric sulfate to yield two important dyestuff intermediates--1,5- and 1,8-disulfonic acid--is also declining. (The anthroquinone vat dyes are of a class that can be easily reduced to a soluble, colorless form in which the fibers are readily impregnated; after this the dyes are oxidized to produce the insoluble color in the fibers.)


Utility Water
Organic Mercurials Production
Process Water 1000 to 2000 GPD 20 to 80 ppm Hg
Continuous Sample and Flow Measurement
Continuous Sample and Flow Measurement
Mercury Removal Process
Total Plant Effluent – 15,000 to 40,000 GPD; Less than 0.5 Lb/Day Mercury
Process Water 5,000 to 12,000 GPD 50 to 150 ppm Hg
Utility Water
Inorganic Mercurials Production
Process and Utility Water
Nonmercurials Production

SOURCE: Ventron Corporation.

Figure 34 WASTEWATER FLOW IN A PLANT PRODUCING MERCURIALS AND NONMERCURIALS


Acetylene and HCl
Catalyst (as HgCl2)
1000
<< 1
<<1
Vinyl chloride (stabilized)
Phenol
Reactor
1000
Refrigerated Column
Column
< 1
< 1
Bottoms to Pot Still
Acetylene
Hydrogen Chloride
Discarded Catalyst
1000
Land

Note: Use of 1,000 kg of mercury as catalyst would account for vinyl production of about 26 million kg – about 10 percent of the production of the industry by this route in 1973.

SOURCE: URS Research Company.

Figure 35 MANUFACTURING PROCESS FOR VINYL CHLORIDE MONOMER, USING A MERCURY CATALYST

The emergence of new synthetic fibers and new dyeing technologies is expected to reduce demand for anthroquinone dyes, with a corresponding decline in mercury usage.

1983 Technology. No important changes or improvements in the technology for making mercurials are forecast. Individual facilities may upgrade equipment in an effort to reduce possible sources of mercury loss to the environment and to improve process efficiency. However, the production of mercurials is small and is not in a growth phase, so that there are no pressures to improve the technology beyond its present limits. Also, the costs involved in the small batch processes now generally in use are dominated by the raw materials cost (primarily for mercury) and small batch sizes allow a degree of flexibility which is quite important to this small industry.

Improvements in the pollution control technology associated with the industry are likely. Although the mercury losses are presently small, continued emphasis upon a clean environment will undoubtedly lead to even more reduction of these losses. For example, rather than directly discharging liquid wastes to sewers after treatment, some plants are now using holding tanks which effectively isolate any accidental spills and prevent their inadvertent discharge to sewers. For 1983, then, we predict that total quantities will be lower and that discharges from production will be about half as great as those for 1973--that is, 0.2 percent of throughput. Examples of the technology which we see as helping to effect this change are discussed briefly below.

Improved methods for removing traces of mercury from water effluents are now in use (see chlor-alkali technology discussion). Basically, these systems depend on the precipitation of mercuric sulfide (by the injection of sodium sulfide) from the waste stream, with collection of the precipitate on a suitable filter. The mercury content of the precipitate is usually recovered either by a retorting process (with control of air emissions) which returns mercury metal to the system, or by a dissolution process which returns mercuric chloride to the system. With either of these technologies, discharges of mercury to the receiving water are reduced to the parts per billion range, and total quantities discharged are well below EPA standards.

Removal of mercury from gas streams (which is not a particular problem in the manufacture of most mercurials) has been of special interest to the chlor-alkali industry. Final traces of mercury in the hydrogen stream from these operations are frequently removed by a final pass through a molecular sieve. Another possible technology involves the use of sulfur-impregnated carbon filter bed. The manufacturer (Pittsburgh Activated Carbon Division of Calgon Corporation) claims its Type HGR activated carbon will reduce mercury concentrations in hydrogen streams from 3 ppm to 1 ppb or less at all gas velocities up to 59 feet per minute (fpm). A mercury recovery of over 95 percent is obtained by retorting.

Development of pollution control devices for a variety of heavy metals is continuing and is likely to accelerate as regulations and standards are developed and applied. Mercury manufacturing and using industries will benefit from these developments, which will likely be aimed at heavy metal emitters with far larger total losses than those involving mercury. As processes are developed which can remove a variety of pollutants in a single pass, the concept of centralized industrial waste treatment facilities may perhaps become a reality; this would increase removal efficiency and decrease overall costs.

Other Considerations. The manufacture of mercurials will continue and will of necessity involve the use of mercury, even though alternative technologies and products are now reducing the total demand for mercurials. (For example, the production of vinyl chloride monomer using other technologies will eliminate the need for mercuric chloride catalysts.) Mercurials are presently a nongrowth industry, with further recession likely in the future.

Mercury losses through theft, a particular problem when a high-value product is involved, will undoubtedly continue to plague the industry. Increased security is one possible answer. Another, perhaps more practical and considerably cheaper answer, is for manufacturers to place increased emphasis upon yields and material balances. Since the processes involved are well known and well documented, expected yields are also well known. Furthermore, analytical techniques are now well developed for tracing mercury losses in waste matter (mostly as an inorganic or organic material in water). Thus the bases for tracking all mercury into and out of a process are now available. If such simple balances were maintained at all times within the plant, abrupt or even subtle changes in balance would immediately alert management to the existence of trouble--probably theft. (While theft may not necessarily indicate a loss of mercury to the environment, the consumer of stolen mercury or mercury compounds will probably have little regard for regulations concerning the control of mercury losses to the environment.)

The storage, handling, and shipping of mercury and its compounds involves a very low volume flow, with only a limited possibility of accidental spills or losses. Mercury metal is almost universally shipped in 76-pound lots, in iron flasks equipped with screw plugs. Flask breakage is virtually impossible, although reports have been received of plugs being loosened with subsequent loss of mercury in transit. However, because of the value of mercury, every effort is made to minimize such losses. According to Ref. 89, the regulations are minimal for surface transport; however air transport is prohibited because of the vunerability of the aircraft's aluminum structure to amalgamation.

Mercury compounds are generally shipped as solids, typically in 50-pound fiberboard drums. Because of the density of the mercurials and the consequent ease of handling, there seem to be very few accidents. The Interstate Commerce Commission (ICC) requires a poison B label on all solid mercury compounds, with a maximum container size of 200 pounds. The International Air Transport Association (IATA) also requires the poison B label for a maximum shipment of 25 kg in the passenger section and 95 kg in the cargo section of a plane. Liquid mercurials (normally a solution or suspension of solid material) are usually shipped in small containers such as 55-gallon drums). According to the ICC they must carry the poison B label, but there is no restriction on container size. The IATA also requires the poison B label, with the same weight limitations as for solid mercury compounds.

Mercury and most of its compounds do not present fire or explosion hazards. (The most obvious exception to this is mercury fulminate, which is a prohibited explosive and is no longer used or available in this country.) However, fires or similar catastrophes involving mercury or its compounds could generate mercury vapor clouds, which could be very dangerous to firefighters or other persons in the immediate area. The use of chemical gas masks, while unlikely to be fully effective against mercury vapor, would certainly be indicated for people downwind of a fire. (In other types of fires involving mercury-containing products, for example a paint warehouse fire, mercury vapors might be released, but the concentrations would probably be so dilute as not to be of major concern.)

Implications. Total estimated mercury losses to the environment from the production of mercurials and from the use of mercurial catalysts in the manufacture of vinyl chloride monomer and vat dyes are shown in Tables 28 and 29, respectively. The estimate for the manufacture of mercurials assumes good control in the present (1973) time frame, with an average loss for each step of production of 0.4 percent of the mercury input. Virtually all of this loss is assigned to water; even for the largest plant identified the estimated discharge to water would not exceed 1 kg per day on this basis (and this does not imply that this manufacturer's losses are necessarily that high). Losses to air are small and, because of industrial safety requirements, these discharges are vented to the atmosphere. Very little solid waste accumulates (as in discarded filter materials), and the solids that do accumulate would be directed to industrial disposal sites.

By 1983 the production of mercurials will have fallen sharply as demand declines, particularly for paint and agricultural usage. Also by 1983, control technology will be adopted that should halve total mercury losses, particularly with respect to water. Thus by 1983 losses to water will be well regulated and controlled.

The losses from the use of mercurial catalysts are only estimates and are based on the assumption that no catalyst recovery is undertaken but that the spent catalyst is discarded to industrial landfills. Hence the total loss for 1973 from catalyst usage is seen as higher than that from all mercurial manufacture (Tables 28 and 29). Of course the final disposal site for catalysts--industrial landfills--is less likely to impinge on man's habitat than is the case for the other mercurials. By 1983 the use of mercurial catalysts for producing VCM and vat dyes will certainly be greatly curtailed, but in our estimates we again assume total loss of the mercury content of the spent catalyst. If recovery processes are instituted, these losses would be greatly decreased.

TABLE 28. - Estimated Mercury Losses from Production of Mercurials, 1973 and 1983[a] (kilograms)

Losses to	1973	1983
Air	80	10
Water	2,800	450
Land	80	20
Totals	2,960	480

a. Estimated losses are based on 0.4 percent and 0.2 percent of throughput for 1973 and 1983 respectively. Throughput is calculated as the total usage of mercury in the Bureau of Mines' use categories of agriculture, catalysts, paint, and pharmaceuticals, which for 1973 totaled 369,419 kg and for 1983 are estimated at 120,000 kg. However, these values have been doubled to account for the numerous intermediate steps in the manufacture of mercurials, which result in double handling (by our estimate) of mercury consumed.

Source: URS Research Company.

TABLE 29. - Estimated Mercury Losses from Use of Manufactured Catalysts in the Production of Vinyl Chloride Monomer and Vat Dyes, 1973 and 1983 (kilograms)

Losses to	1973	1983
Air	50	15
Water	100	30
Land	18,850	6,955
Totals	19,000	7,000

Source: URS Research Company

Battery Manufacturing (SIC 3692)

The battery manufacturing industry consumed approximately 16,260 flasks, or 30 percent, of the mercury used in the United States in 1973.* According to a recent report on the industry by Versar, Inc. (Ref. 69), in the battery manufacturing process the loss of mercury to the environment was only about 82 flasks, or 0.5 percent of the mercury used by the industry. Most of the mercury lost in this manner was deposited in landfill sites near the manufacturing plants. Some 95 percent of the mercury lost from the battery manufacturing and use cycle occurs when the batteries are thrown away by the consumer, with 92 percent of this going to landfill and 8 percent to public incineration. The remaining wastes are recycled by the government, industry, or manufacturers.

Mercury is used in the manufacture of zinc-carbon dry cells, alkaline-manganese dioxide dry cells, mercury cells (Reuben, Weston, and mercury-cadmium cell), zinc-silver oxide cells, and carbon-zinc air cells. All of these batteries are manufactured within SIC group 3692 (primary batteries), except for the zinc-silver oxide battery, which is in SIC group 3691 (storage batteries). In the following technological analysis, however, only the zinc-carbon, alkaline-manganese dioxide, and Ruben mercury batteries are considered, because they account for 99.5 percent of the industry's mercury losses (Ref. 69). These mercury losses, by battery type, are shown in Figure 36.

The average annual growth rate of the battery industry from 1963 to 1973 was 4.3 percent. The industry is expected to grow at about 4.5 percent annually from 1973 to 1985 (Ref. 71). Developments in battery technology and new applications for batteries will be the prime motivators for this continued growth; for example, battery uses will expand with the development of electric vehicles as a means of avoiding the increasing costs of fossil-fuel burning vehicles.

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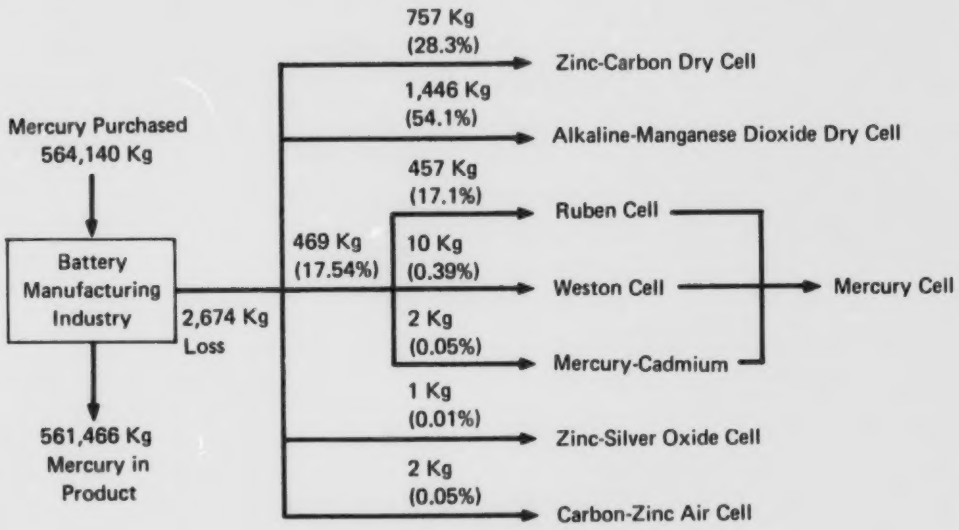
* Best estimates based on Ref. 14. This value is approximately one-third higher than that reported in Ref. 69.


Mercury Purchased
564,140 Kg
Battery Manufacturing Industry
561,466 Kg Mercury in Product
2,674 Kg Loss
757 Kg (28.3%)
Zinc-Carbon Dry Cell
1,446 Kg (54.1%)
Alkaline-Manganese Dioxide Dry Cell
469 Kg (17.54%)
457 Kg (17.1%)
Ruben Cell
10 Kg (0.39%)
Weston Cell
2 Kg (0.05%)
Mercury-Cadmium
Mercury Cell
1 Kg (0.01%)
Zinc-Silver Oxide Cell
2 Kg (0.05%)
Carbon-Zinc Air Cell

SOURCE: Ref. 70.

Figure 36 MERCURY LOSS IN MANUFACTURING, BY TYPE OF BATTERY, 1973

The three major consumer categories for the battery industry are the public, industry, and government. In 1973, 70.5 percent of U.S. battery shipments went to the public, 19.4 percent to industry, and 10.1 percent to the government. By 1983, shipments to these sectors are expected to be 72.7 percent to the consumer, 19.7 percent to industry, and 7.6 percent to the government (Ref. 71).

For over a century, until the early 1960s, the primary battery market was dominated by the zinc-carbon battery. Recently, however superior electrode materials have been developed that pose a competitive threat to the zinc-carbon cell. This type of battery represented 54 percent of the primary battery market in 1973, but it is expected that by 1985 it may account for only 36 percent of the market (Ref. 71).

In contrast, the alkaline-manganese dioxide battery's popularity increased very rapidly during the last decade. In 1973 this battery accounted for 22 percent of the mercury battery market, and it is expected to account for 34 percent of the market by 1985 (Ref. 71). The chief causes of this growth are the superior energy characteristics and less expensive costs.

Mercury cells are expected to account for some 7 percent per year of the primary battery market between 1973 and 1985 (Ref. 71). These cells will have a steady share of the market because of their specialized uses as small, reliable, and long-life power sources. The remaining primary batteries should continue to account for about 23 percent of the market over the next decade (Ref. 71). The batteries included in this group are silver-zinc, ammonia-activated, cadmium-mercury, metal-air, solid-state, organic electrolyte, lithium, and sodium-bromine.

Production Sites. In the United States there are 21 plants that manufacture zinc-carbon batteries, 7 plants that manufacture alkaline-manganese dioxide batteries, and 7 plants that manufacture Ruben mercury batteries (Ref. 69). Of these, Union Carbide, ESB Inc. (Ray-O-Vac), P. R. Mallory, and Gould Corporation (Burgess) accounted for 85 percent of the battery sales in 1973 (Ref. 71). Table 30 shows plant locations of the principal manufacturers, by state, and indicates the approximate mercury losses to the environment from these plants

TABLE 30. - Major U.S. Battery Manufacturers' Mercury Losses, by Plants and State, 1973 (kilograms)

Region and State	Manufacturer and Type of Battery Manufactured[a]	Losses to the Environment			Total Losses
		Land	Water	Air	
Atlantic					
Connecticut	C-Z	<1	-	-	<1
Vermont	C-Z, A-M, Hg	29	<1	2	32
	C-Z, Other	3	-	<1	4
New Jersey	C-Z	9	-	<1	10
	C-Z, Other	<1	12	<1	13
	C-Z	8	-	<1	8
New York	Hg	127	3	7	136
North Carolina	C-Z, A-M, Other	129	3	7	138
	C-Z, A-M, Hg	439	9	19	467
		36	1	2	39
Pennsylvania	C-Z, A-M	43	1	2	46
Rhode Island	Other	3	-	-	3
South Carolina	C-Z, Hg	6	-	<1	7
Subtotal[b]		833	29	42	902
North Central					
Illinois	C-Z, Hg	101	2	5	109
Iowa	C-Z	27	<1	2	29
Missouri	Other	3	-	-	3
Ohio	C-Z, Other	224	5	12	241
	C-Z	93	2	5	101
Tennessee	A-M	135	3	7	145
	A-M	34	1	2	36
Wisconsin	C-Z, A-M, Hg	998	20	54	1,073
	C-Z	14	-	1	15
	C-Z, Other	14	-	1	15
Subtotal[b]		1,643	33	89	1,767
Total		2,476	62	131	2,670

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a. In some instances, a manufacturer may have more than one plant in a state, Battery types are designated as follows: C-Z = carbon-zinc dry cell; A-M = alkaline-manganese dioxide dry cell; Hg = Ruben mercury cell.

b. Totals may not add, due to rounding.

Source: Derived by URS from Ref. 70.

in 1973. (As previously mentioned, only plants manufacturing zinc-carbon, alkaline-manganese dioxide, and Ruben mercury cells are considered in this analysis.) As the table shows, all of the significant mercury-consuming plants are located in the Atlantic and North Central regions of the country. About 34 percent of the mercury losses in battery manufacturing occurred in the Atlantic region and 66 percent in the North Central region. (Note the predominance of manufacturing and losses in Wisconsin and North Carolina.)

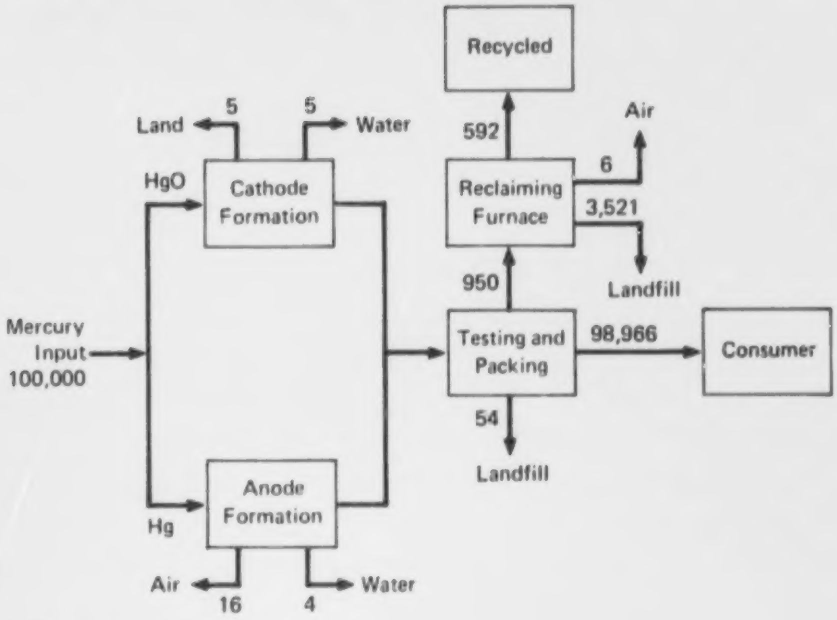
1973 Technology. The present battery manufacturing technology is most readily discussed in terms of types of batteries.

Zinc-Carbon Dry Cells. Although mercury is frequently used to amalgamate zinc, its primary use in this process is as a paste (mercury chloride) applied to paperboard separators. Mercury losses during these operations are comparatively small.

The major loss of mercury during the manufacture of zinc-carbon batteries occurs when batteries are rejected during inspection, testing, and packaging. Normally, these rejects are sent to local landfill sites for disposal. The amount of mercury wastes from rejected batteries represents 7.3×10^{-6} kg of mercury per kilogram of batteries produced. The total annual mercury loss from all plants that manufacture zinc-carbon is 756.4 kg (1,668 lbs) (Ref. 70). Presently there is no technology to allow economical recycling of these rejected batteries. However, the zinc-carbon batteries that are thrown away by the ultimate consumer represent the most significant loss of mercury to the environment (mostly to landfills or public incineration).

Alkaline-Manganese Dioxide Dry Cells. Mercury is amalgamated with powdered zinc to form the anode. This is normally done in a closed system, so that there is very little mercury loss. Again, the primary loss of mercury occurs when rejected batteries are disposed of in landfill sites. This estimated loss is 7.6×10^{-6} kg of mercury per kilogram of battery (Ref. 70). Annual mercury losses of all the U.S. alkaline-manganese dioxide battery plants are estimated to total 1,445 kg (3,187 lbs). Rejected batteries are not recycled by the manufacturers, because such recycling is not economical.

Ruben Mercury Batteries. A typical flow diagram for a Ruben mercury cell battery plant is shown in Figure 37. The anode of the mercury cell is


Recycled
Land
5
5
Water
592
Air
HgO
Cathode Formation
6
Reclaiming Furnace
3,521
950
Landfill
Mercury Input 100,000
Testing and Packing
98,966
Consumer
54
Landfill
Anode Formation
Hg
Air
16
4
Water

SOURCE: URS Research Company.

Figure 37 FLOW DIAGRAM OF MERCURY LOSSES DURING MANUFACTURE OF RUBEN MERCURY CELL BATTERIES

produced by amalgamating zinc with metallic mercury. The cathode is fabricated by pressing red mercury oxide with graphite. As shown in the diagram, during these operations very little mercury is lost to the environment. In contrast to the manufacture of the other two types of batteries, however, 95 percent of the rejected Ruben cells are processed to reclaim mercury. The other 5 percent are sent to landfill sites. Mercury is recovered from the rejected cells by incineration in a reclaim furnace; the recovery of mercury here is approximately 1.6×10^{-3} kg mercury oxide and 0.39×10^{-3} kg mercury per kilogram of product (Ref. 69). Any unreacted residue containing mercury is disposed of in a landfill. In this process, the total loss of mercury to landfill is 1.88×10^{-3} kg of mercury per kilogram of product (1.49×10^{-3} kg from mercury oxide and 0.39×10^{-3} kg from metallic mercury). Estimated total annual mercury losses from Ruben mercury cell plants are 457.4 kg (1,009 pounds). Again, however, the most significant losses occur when consumers discard the spent batteries (in public landfill sites or incinerators).

Technology in 1983. Because relatively small amounts of mercury are lost during battery manufacture, few changes in manufacturing processes are expected by 1983. However, there will probably be more recycling of rejected batteries during the next five to ten years. The major reason for this is that the cost of zinc is rising so rapidly that recycling is becoming economically justifiable. In addition, if industry and consumers follow the lead of the many federal agencies that now sell spent mercury batteries for scrap value, the total mercury loss to landfill and incineration should decrease markedly in the next ten years.

Estimates of mercury losses from primary battery production and consumption for 1973 and 1983 are given in Table 31. Primary battery production is expected to increase 45 percent during the decade, but tight mercury controls should keep annual manufacturing losses down to about 0.5 percent of the mercury used (for an estimated manufacturing loss of 3,876 kg in 1983). Mercury losses to landfill that result from consumers disposing of old batteries will grow by 31 percent if recycling approaches 10 percent (currently it is about 5 percent) and decrease by 27 percent if extensive recycling (50 percent) is implemented.

TABLE 31. - Estimated U.S. Battery Manufacturing and Related Consumer Losses of Mercury, 1973 and 1983
(kilograms)

Type of Primary Battery	1973 Losses		1983 Losses		
				Consumer	
	Manufacturer	Consumer	Manufacturer	Technology Level	Losses
Zinc-Carbon	756	157,847	926	High	97,190
				Low	174,940
Alkaline-Manganese	1,445	301,752	2,270	High	240,170
				Low	445,200
Mercury	469	98,165	680	High	71,640
				Low	116,060
Total	2,671	557,764	3,876	High	409,000
				Low	736,200

Source: URS Research Company

Alternative Technologies. Battery manufacturers have done an excellent job of controlling mercury losses during manufacture. However, substantial losses to the environment occur when the consumer disposes of old batteries. If these losses cannot be controlled by recycling, and if such losses cannot be tolerated, substitutes may have to be found for most mercury cells.

Batteries which do not require mercury are expected to account for 23 percent of the primary battery market by 1983, even in the absence of controls on mercury use (Ref. 71). If environmental controls are enacted to eliminate mercury from batteries, of course, the manufacturing picture will be drastically altered. Primary batteries which might be substituted for most of the mercury cells include silver-zinc, ammonia-activated, metal-air, solid-state, organic electrolyte, lithium, and sodium-bromine cells. However, many of the materials (cadmium, chromium, copper, lead, and zinc, among others) used in these cells also have adverse environmental properties, and no other material has been developed that has the electrolytic properties of mercury. Extensive research and development will be required before alternate types of cells will be able to compete seriously with mercury.

Electric Lamp Manufacturing (SIC 3641)

The electric lamp manufacturing industry consumed approximately 1,258 flasks (43,360 kg), or 2.3 percent, of the mercury used in the United States in 1973 (Ref. 14). During electric lamp manufacture, however, only 50 flasks (1,723 kg) of the mercury used by the industry were lost to the environment (Refs. 10, 12). Most (95 percent) of the mercury lost in manufacturing went to nearby industrial landfill sites; the remaining losses were to air. The greatest losses occurred when lamps were discarded by consumers, with 95 percent going to landfill and 5 percent to incineration, according to the URS inventory.

Mercury has been used in lamp manufacture since the late 19th Century, but its use in this application was not significant until 1938 (Ref. 72). From then until 1963 total lamp shipments increased at an annual rate of 6.5 percent. From 1963 to 1973, however, lamp shipments increased only 2.9 percent annually, and by 1983 they are expected to increase only 2 percent annually (Ref. 73). The chief reasons for the slowdown in lamp shipments are the increased popularity of long-life lamps and the use of larger lamps with more lumens per watt (more light output at lower cost). It is important to note, however, that these larger lamps (most of which are fluorescent) have had an annual rate of increase in shipments of 5.5 percent, and this figure is expected to increase to 5.7 percent (Ref. 73).

Discharge lamps which use mercury are of the fluorescent, mercury vapor, metal halide, and high-pressure sodium types. These lamps, which are manufactured within SIC group 3641, are used primarily for lighting streets and highways, high-ceiling rooms, motion picture projection, photography, dental examinations, photochemistry, heat lamps, and water purification.

Typically, discharge lamps require the following amounts of metallic mercury: a 40-watt, 4-foot fluorescent lamp requires 40 mg of mercury and a 75-watt, 8-foot lamp uses 50 mg; a 400-watt mercury vapor lamp contains 60 to 76 mg of mercury; a 400-watt metal halide lamp requires between 50 and 60 mg of mercury; and a 400-watt high-pressure sodium lamp needs 20 to 30 mg of mercury (Ref. 74).

In the following technological analysis, only fluorescent lamps are considered, because they utilize 95 percent of the mercury used in lamp manufacturing. Also, fluorescent lamps comprise 30 percent of total lamp shipments, compared to about 2 percent for any of the other mercury lamps; all mercury lamps contain about the same amount of metallic mercury; and manufacturing procedures for all the mercury lamps are fairly similar.

Production Sites. Approximately 69 U.S. plants manufactured electric lamps in 1973 (Ref. 75). Of these, 47 manufactured mercury lamps. GTE-Sylvania, Westinghouse Electric, General Electric, and North American Phillips accounted for about 90 percent of the total SIC 3641 sales (Ref. 73). Table 32 lists the number of mercury lamp manufacturers, by state, and shows approximate mercury losses to the environment. As the table indicates, most of the mercury lamp manufacturing plants are located in the Atlantic and North Central U.S. regions of the United States. The five states that together account for 73 percent of the mercury losses are Ohio (23 percent), Massachusetts (15 percent), Kentucky (13 percent), North Carolina (11 percent), and New Jersey (11 percent).

TABLE 32. - Estimated Mercury Losses from Electric Lamp Manufacturing in the United States, by State, 1973
(kilograms)

Region and State	No. of Major Mercury Lamp Manufacturers	Estimated Losses to the Environment		Total Environmental Loss
		Air	Land	
Atlantic				
Massachusetts	3	13	244	257
New Hampshire	1	3	57	60
New Jersey	6	9	180	189
New York	1	2	38	40
North Carolina	1	1	14	15
Pennsylvania	7	10	185	195
West Virginia	1	3	58	61
Subtotal	20	41	776	817
North Central				
Illinois	3	4	76	80
Kansas	1	1	14	15
Kentucky	6	12	219	231
Missouri	1	1	20	21
Ohio	8	20	386	406
Oklahoma	1	-	5	5
Tennessee	2	3	47	50
Subtotal	22	41	767	808

TABLE 32. - Estimated Mercury Losses from Electric Lamp Manufacturing in the United States, by State, 1973
(kilograms)
(continued)

Region and State	No. of Major Mercury Lamp Manufacturers	Estimated Losses to the Environment		Total Environmental Loss
		Air	Land	
South				
Alabama	1	2	31	33
Arkansas	1	2	33	35
Mississippi	1	1	20	21
Texas	1	1	14	15
Subtotal	4	6	98	104
West				
California	1	-	4	4
Subtotal	1	0	4	4
United States Total	47	88	1,645	1,733

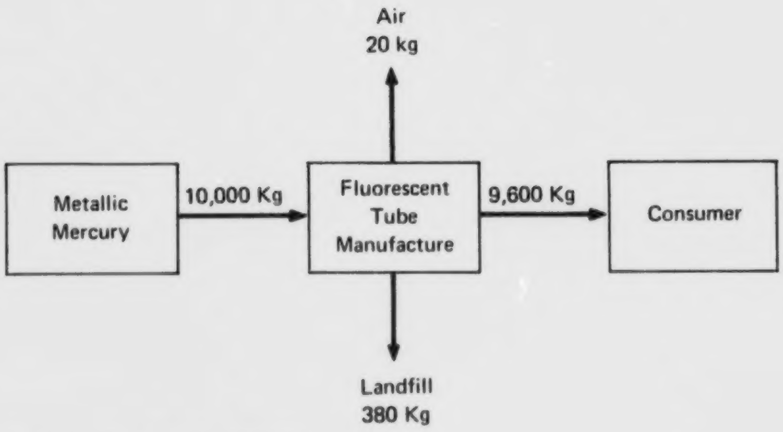
Source: URS Research Company

1973 Technology. A flow diagram for a typical fluorescent lamp plant is shown in Figure 38. The metallic mercury, starting gas (normally argon), and other materials are injected into a quartz tube which is then sealed. During this process, very little mercury is lost to the environment. Small losses to air occur when the mercury is spilled (and later vaporized) and when tubes are broken during manufacture and testing, which represent perhaps 5 percent of total manufacturing losses. The greatest manufacturing losses occur when rejected tubes are sent to industrial landfills for final disposal. Such estimated annual losses total about 1,733 kg, or 95 percent of the manufacturing losses. The fluorescent tubes that are thrown away by the ultimate consumer, however, represent the most significant loss of mercury--some 41,660 kg annually--to the environment (mostly to landfills or public incineration).

1983 Technology. Because mercury losses during manufacturing are relatively small, few changes in the use of mercury during lamp manufacture are expected by 1983. Of course, recycling or careful disposal of spent fluorescent tubes could occur by that date, but it seems likely that the economics of recovering the mercury from spent tubes would not warrant recycling. The only possible reduction of mercury usage by this industry would come from substituting some other, as yet unknown, material for mercury.

A comparison of estimated mercury losses from lamp manufacturing and use in 1973 and 1983 is given in Table 33. The proportion of electric lamps using mercury is expected to increase about 50 percent by 1983, but due to tight controls, mercury loss during manufacture is expected to be only 4 percent of the total input, or perhaps 2,700 kg. If recycling approaches 5 percent of all lamps sold to consumers, mercury losses to landfill by consumers will increase by 43 percent.

Alternative Technologies. Manufacturers of mercury lamps have done an excellent job of controlling internal plant losses of mercury. Substantial losses to the environment occur, however, when consumers discard spent tubes. If such losses are not tolerable, substitutes for mercury or mercury lamps will have to be developed, but most mercury lamp manufacturers indicate that no other satisfactory substitute for mercury in discharge lamps has been found (Refs. 74, 76). With extensive research and development and increased


Air
20 kg
Metallic Mercury
10,000 Kg
Fluorescent Tube Manufacture
9,600 Kg
Consumer
Landfill
380 Kg

SOURCE: URS Research Company.

Figure 38 FLOW DIAGRAM OF ESTIMATED MERCURY LOSSES DURING MANUFACTURE OF FLUORESCENT LAMPS

TABLE 33. - Estimated Mercury Losses from Lamp
Manufacturing and Use, 1973 and 1983
(kilograms)

Type of Lamp	1973		1983	
	Manufacturing Losses	Consumer Losses	Manufacturing Losses	Consumer Losses[a]
Fluorescent	1,671	40,227	2,623	57,324
Mercury Vapor	62	1,437	74	2,048
Total	1,733	41,664	2,697	59,372

a. Assuming a 5-percent recycling rate.

Source: URS Research Company

expenditures, a substitute may be developed in the future, but the efficiency of such a substitute is only conjectural at this time.

Other lamps which do not require mercury are available, and in fact comprise most of the current market. Most of these are incandescent metal filament lamps and cannot match mercury lamps in electrical efficiency or for many specialized purposes. Although fluorescent lamps operate under a higher voltage than other nonmercury lamps, they give off more lumens per watt of energy, thus requiring less overall energy consumption. Fluorescent lamps also portray colors more accurately, have a longer life than most other tubes, and have a higher efficiency than conventional lamps (Refs. 72, 74, 77, 78). If other lamp types without improved efficiency were substituted for fluorescent lamps, the United States would require more energy output from its electric power plants in order to maintain current lighting levels.

Another advantage which conventional lamps have not duplicated is that mercury vapor lamps can give off high levels of ultraviolet radiation. Ultraviolet ray lamps are used extensively for therapeutic purposes, improved photocopying, photochemistry, and as germicides (most notably for water purification) (Ref. 77). If these special-purpose lamps were removed from the market, substitutes would be needed to replace them.

Industrial Instruments (SIC 3613 and 3821)

The industrial instrument industry in the United States comprises many SIC groups, including electric measuring instruments (3611); switchgear and switchboard apparatus (3613); industrial controls (3622); engineering and scientific instruments (3811); mechanical measuring and control instruments (3821); environmental controls (3822); process control instruments (3823); fluid meters and counting devices (3824); and photographic equipment and supplies (3861). This report, however, deals directly with only two of these groups, SIC 3613 and SIC 3821.

In 1973 the entire industrial instrumentation industry consumed approximately 7,155 flasks, or 13 percent, of the mercury used in the United States (Ref. 14). For several reasons, this mercury consumption was limited almost exclusively to metallic mercury. Metallic mercury is liquid at ordinary temperatures (melting point -38.87°C), with high electrical conductivity; it has excellent high thermal conductivity and regular thermal expansion. Because of these properties, mercury metal is readily adaptable for use in many instruments. Some of the major types of instruments that use mercury are thermometers, thermostats, and thermoregulators; flowmeters (manometers); pressure-sensing devices and barometers (now largely the nonmercury aneroid types); gages; valves; pump seals; switches and relays; navigational devices (gyroscopes, artificial horizons, etc.); and medical devices (red blood cell counters, blood CO_2 analyzers, etc.).

URS estimates that 81 percent, or 199,932 kg, of the 246,612 kg of mercury consumed in instrument manufacturing in 1973 was used by the control instrument industry (SIC 3821) and 19 percent (46,680 kg) was consumed by the switch and relay industry (SIC 3613). About 55 percent (133,908 kg) of the mercury consumed by the instrument industry was recycled or reclaimed (secondary) mercury (Ref. 10). The control instrument industry losses during manufacture are estimated to be 1 percent (2,000 kg), and the switch and relay instrument losses are estimated to be 2.5 percent (1,169 kg).

Overall, the mercury-using industrial instrument manufacturing industry is expected to grow 14 percent between 1973 and 1983. With the introduction of solid-state devices and new designs, however, the consumption of mercury for manufacturing switches is expected to decline 20 percent between 1973 and 1983. The relay and other instrument industries, on the other hand, are expected to increase their consumption of mercury by 14 to 20 percent.

Production Sites. Table 34 lists the industrial instrument manufacturers for SIC 3613 and 3821 by state and shows estimates of their mercury losses to the environment in 1973. It is difficult to determine specifically what instrument manufacturers are of concern, because of the number of SIC groups involved and the varied types of instruments marketed within each SIC group. The basis for this table, however, was the value of shipments added by manufacture for the switch and relay industry (SIC 3613) and for industrial control instruments (SIC 3821). The results indicate that although the switch and relay manufacturers used only 19 percent of the two groups' total mercury consumption in 1973, their losses (1,169 kg) represented 37 percent of the total mercury losses

TABLE 34. - Estimated Mercury Losses from Industrial Instrument Manufacturing, by State, 1973
(kilograms)

Region and State	Losses from Switch and Relay Manufacturing			Losses from Control Instrument Manufacturing			Total Losses
	Land	Air	Total	Land	Air	Total	
Atlantic							
Connecticut	79	4	83	161	9	170	253
Florida	5	1	6	8	-	8	14
Georgia	38	1	39	19	1	20	59
Maine	12	1	13	-	-	-	13
Maryland	12	1	13	-	-	-	13
Massachusetts	28	1	29	310	16	326	355
New Hampshire	5	1	6	-	-	-	6
New Jersey	71	4	75	57	3	60	135
New York	28	1	29	298	16	314	343
North Carolina	28	1	29	19	1	20	49
Pennsylvania	271	15	286	298	16	314	600
Rhode Island	-	-	-	19	1	20	20
South Carolina	4	-	4	-	-	-	4
Vermont	-	-	-	19	1	20	20
Virginia	12	1	13	-	-	-	13
Subtotal	593	32	625	1,208	64	1,272	1,897
North Central							
Illinois	111	6	117	218	12	230	347
Indiana	28	1	29	19	1	20	49
Iowa	28	1	29	21	1	22	51
Kentucky	52	3	55	6	-	6	61
Michigan	13	1	14	46	2	48	62

TABLE 34. - Estimated Mercury Losses from Industrial Instrument Manufacturing, by State, 1973
(kilograms)
(continued)

Region and State	Losses from Switch and Relay Manufacturing Land	Air	Total	Losses from Control Instrument Manufacturing Land	Air	Total	Total Losses
North Central							
Minnesota	12	1	13	-	-	-	13
Missouri	61	3	64	6	-	6	70
Nebraska	12	1	13	6	-	6	19
Ohio	39	2	41	133	7	140	181
Oklahoma	-	-	-	4	-	4	4
Tennessee	5	1	6	4	-	4	10
Wisconsin	28	1	29	34	2	36	65
Subtotal	389	21	410	497	25	522	932
South							
Arkansas	5	1	6	-	-	-	6
Mississippi	12	1	13	-	-	-	13
New Mexico	-	-	-	6	-	6	6
Texas	26	1	27	40	2	42	69
Subtotal	43	3	46	46	2	48	94
Mountain							
Colorado	-	-	-	40	2	42	42
Subtotal	-	-	-	40	2	42	42

TABLE 34. Estimated Mercury Losses from Industrial Instrument Manufacturing, by State, 1973
(kilograms)
(continued)

Region and State	Losses from Switch and Relay Manufacturing			Losses from Control Instrument Manufacturing			Total Losses
	Land	Air	Total	Land	Air	Total	
West							
Arizona	6	1	7	-	-	-	7
California	68	3	71	104	6	110	181
Oregon	4	-	4	6	-	6	10
Washington	5	1	6	-	-	-	6
Subtotal	83	5	88	110	6	116	204
Total	1,108	61	1,169	1,901	99	2,000	3,169

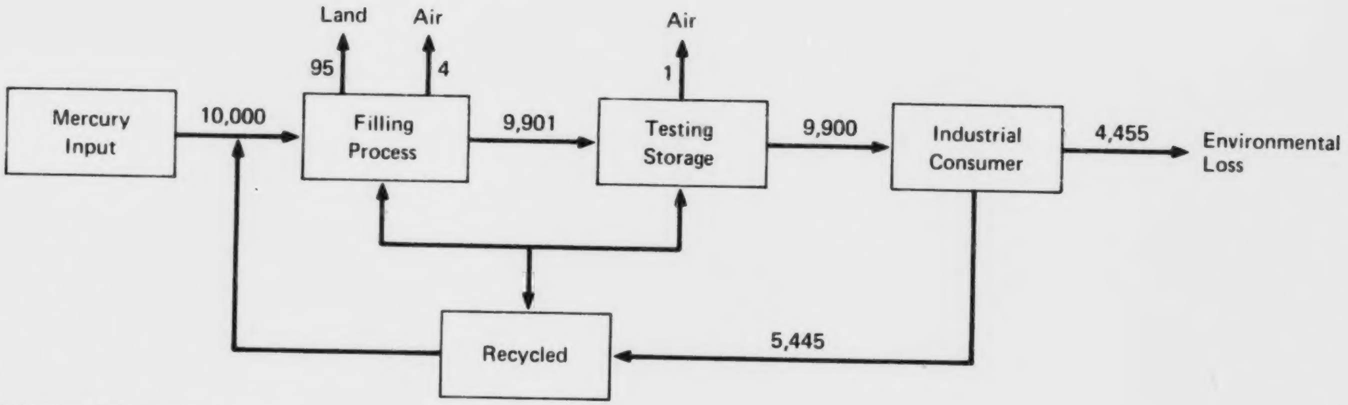
Source: Derived by URS from 1967 Census of Manufacturers.

to the environment. The control instrument manufacturers, on the other hand, used 81 percent of the mercury but their in-plant losses were only 63 percent (2,000 kg) of the total.

1973 Technology. Figure 39 is a flow diagram of mercury losses during a typical control instrument manufacturing process, and Figure 40 is a flow diagram of relay and switch manufacturing losses. During control instrument manufacture, mercury is lost primarily in the filling process, when the tubes or receiver bodies are loaded with accurately measured amounts of mercury. Losses occur through spillage (to land), volatilization (to air), and in cleaning old instruments that require servicing (to land). Minor mercury losses, mostly air, also occur when leaks develop during testing and storage of the instruments. In total, however, we estimate that only about 1 percent of the mercury consumed by the control industry is lost in the manufacturing process. About 95 percent of this loss is to land, and the remaining 5 percent is to air. (Mercury losses to water are insignificant, because water is not required during the filling process and the number of instruments that must be water tested is very small.)

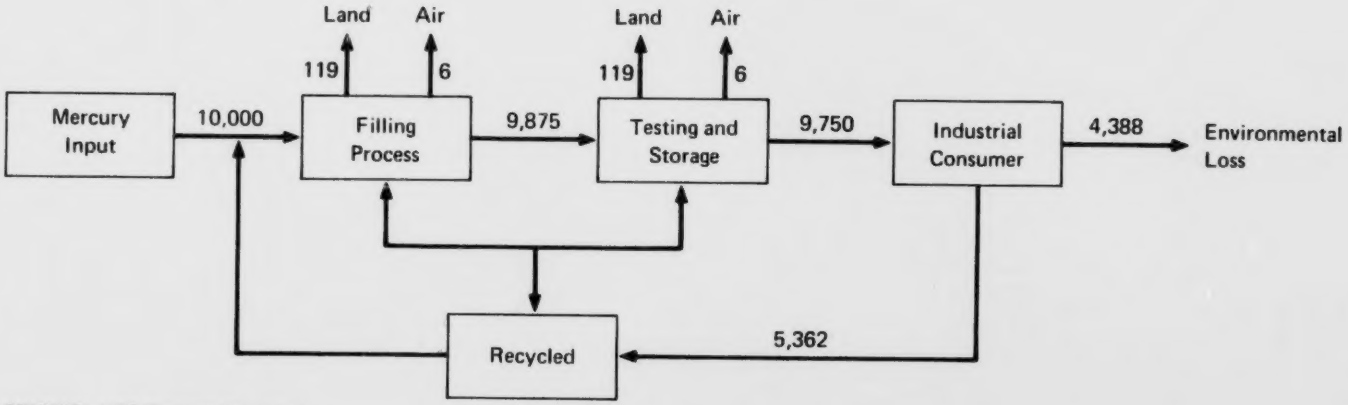
In the switch and relay manufacturing process, the principal mercury losses occur during filling and testing (see Fig. 40). Because switches and relays are smaller and use less mercury than do most of the control instruments, losses to land during filling total only about 50 percent of the manufacturing loss, and this loss is only 1.2 percent of the total mercury used in the manufacturing process. About the same percentage of the total mercury used in manufacturing is lost to land when switches and relays are tested. The remaining very slight manufacturing losses (0.1 percent) are to air and are evenly divided between the filling and testing processes.

The overwhelming majority of mercury losses to the environment that are associated with industrial instruments occur during consumer use and disposal of the finished products. Industrial consumers recycle substantial amounts of mercury back to the manufacturers (approximately 55 percent), usually when instruments are traded in for new models or are serviced. The most significant consumer losses occur when individual small consumers discard instruments--such as thermometers, small manometers, or switches--after they have served their purpose.


Land
Air
Air
95
4
1
Mercury Input
10,000
Filling Process
9,901
Testing Storage
9,900
Industrial Consumer
4,455
Environmental Loss
Recycled
5,445

SOURCE: URS Research Company.

Figure 39 FLOW DIAGRAM OF MERCURY LOSSES IN TYPICAL CONTROL INSTRUMENT MANUFACTURING PROCESS


Land
Air
119
6
Land
Air
119
6
Mercury Input
10,000
Filling Process
9,875
Testing and Storage
9,750
Industrial Consumer
4,388
Environmental Loss
Recycled
5,362

SOURCE: URS Research Company.

Figure 40 FLOW DIAGRAM OF MERCURY LOSSES IN TYPICAL SWITCH AND RELAY MANUFACTURING PROCESS

1983 Technology. Little or no change is expected in the mercury-related technology of instrument manufacturing by 1983. Except for increases that accompany the normal and expected growth of the industry, mercury consumption and losses to the environment should remain stable through 1983. A 14-percent growth rate is expected for the industry (and hence for its consumption of mercury) between 1973 and 1973. Therefore, Table 35 is based on the assumption that mercury losses to the environment will also increase by about 14 percent.

Alternative Technologies. Very little mercury is discharged to the environment during industrial instrument manufacturing (1.0 percent of the mercury consumed by the control instrument industry and 2.5 percent of that consumed by the switch and relay industry). The significant mercury losses to the environment occur when consumers dispose of instruments to local landfills. Either mercury would have to be replaced by other materials, or mercury-containing instruments would have to be completely recycled, in order to reduce present loss rates significantly.

Many substitute devices for certain mercury instruments are presently available. Temperature-sensing devices which can be substituted for mercury-in-glass thermometers (probably the most significant mercury-consuming instruments) include alcohol-in-glass thermometers; thermistors (devices in which current changes are directly proportional to temperature); thermocouples (most popular are copper-constantan, iron-constantan, chromalumel, and platinum/platinum-rhodium); bimetallic strips; and pyrometers (optical and radiation). Replacements for mercury manometers (a device for measuring fluid pressures under steady-state condition) and mercury barometers (a type of manometer used to measure atmospheric pressures) include Bourdon tubes, diaphragms and bellows, Bridgman and Pirani gages (using electrical resistance), ionization gages (including a vacuum tube), and alphatrons (radioactive ionization tubes). Many solid-state devices are also in development or production which may replace other mercury instruments. The problem in the use of these devices is to get consumers to accept them as desirable alternatives. Because mercury instruments are generally cheaper and are highly reliable, instrument users are reluctant to change quickly to newer, more expensive, and less proven instruments.

TABLE 35. - Estimated Mercury Losses from Industrial Instrument Manufacture and Use, 1973 and 1983 (kilograms)

Losses to	1973 Losses from Manufacturing	1973 Losses from Consumer Use	1983 Losses from Manufacturing	1983 Losses from Consumer Use
Land	3,009	100,780	3,430	114,895
Air	160	8,763	182	9,991
Total	3,169	109,543	3,612	124,886

Source: URS Research Company

The other alternative for controlling mercury losses to the environment--complete recycling of used mercury instruments--would be difficult to accomplish. As indicated earlier, most industries already recycle many of their instruments. If more emphasis is placed on recycling, industries may increase their recycling rate from the 1973 figure of 55 percent to as much as 75 percent by 1983. However, many private and small consumers (who break instruments and spill mercury on the ground or down the sink) cannot recycle instruments, and such losses will doubtless continue to represent a major discharge to the environment.

Paint Manufacturing (SIC 2851)

The paint manufacturing industry consumed 7,603 flasks, or 14 percent, of the mercury used in the United States in 1973 (Ref. 14). A small amount (32 flasks) of this was used for mildewproofing substances, and the remainder (7,571 flasks) went into paint additives. According to the URS inventory results, the total loss of mercury to the environment from paint manufacturing was only about 95 flasks (3,272 kg), or 1.2 percent of the mercury used by the industry. The largest environmental loss occurs when the paint is used by the ultimate consumer; overall losses for all paint usage are discussed under "Macrotechnology."

The use of phenylmercuric compounds as preservatives and mildewcides dates back to the late 1930s, but their use in latex paint did not become significant until after World War II. In the early 1950s, when paint film defects were diagnosed as mildew growth, the paint industry started using phenylmercuric compounds extensively. However, latex paint did not become popular as a household paint until the early 1960s. Various ingredients based on other nonmercury compounds were used but were abandoned because of adverse physical characteristics and inadequate performance (most noticeably fluorescence, yellowing, and viscosity changes within the paint). Phenylmercuric compounds were found to be more reliable and less expensive, and it was possible to use them in low concentrations. Today, phenylmercuric compounds are used chiefly as a preservative in water-thinned paint (latex) to prevent bacterial growth, and as a mildewcide in both latex and solvent paints for exterior surface protection to prevent fungus growth on the applied paint film.

Phenylmercuric compound additives are used in small amounts (less than 0.02 percent by weight in interior paint and less than 0.2 percent in exterior paint) with supposedly low orders of toxicity. The most common mercuric additives in paint are phenylmercuric acetate and phenylmercuric oleate (Ref. 79). Phenylmercuric acetate contains approximately 18 percent mercury and is slightly soluble in water (about 600 ppm), while the phenylmercuric oleate contains approximately 11 percent mercury and is insoluble in water.

The Federal Insecticide, Fungicide, and Rodenticide Act requires that all pesticide products be registered with the EPA before they can be marketed in interstate commerce. Phenylmercuric compounds used in paints are included in this category. Because of the high mercury content of many U.S. harbors (Ref. 13), which was suspected to be connected to losses of mercury from antifouling paints, most mercury compounds used in marine antifouling paints had been removed prior to March 22, 1972, when the EPA published an order in the Federal Register (PR Notice 72-5) to suspend or cancel all alkylmercury pesticides because of their highly toxic and cumulative effects on living organisms. Recently the EPA has reviewed this use and has taken action to ban the mercurials completely. The paint industry and other groups, however, are appealing this ruling, and hearings are under way to determine if the use of mercury should be curtailed.

Nonmercury paint additives have been recently marketed; most of these products contain tin, copper, or boron. There are presently several disadvantages to using these substitutes in paint: the cost of the substitutes is higher (estimated to be as much as 25 percent higher); they must be used in high concentrations; their effectiveness in paint, both in the can and on applied surfaces, has not matched that of mercury; and their long-term environmental safety has not been established.

Production Sites. Table 36 lists approximate mercury losses to the environment from U.S. paint manufacturing operations in 1973. As the table shows, there are a great many manufacturing plants, relatively evenly distributed in

TABLE 36 . - Mercury Losses from U.S. Paint Manufacturing Operations, by State, 1973 (kilograms)

	Number of Establishments with		Mercury Losses to			
Region and State	Less than 20 Employees	More than 20 Employees	Land	Air	Water	Total
Atlantic						
Connecticut	15	2	52	6	14	72
Delaware	4	2	7	1	2	10
Florida	71	14	40	5	11	56
Georgia	37	17	55	7	15	77
Maine	3	1	15	2	4	21
Maryland	28	18	40	5	11	56
Massachusetts	52	21	80	10	23	113
New Hampshire	3	1	11	1	3	15
New Jersey	154	69	106	13	30	149
New York	151	47	201	25	56	282
North Carolina	18	11	84	10	24	118
Pennsylvania	68	36	177	22	52	251
Rhode Island	10	3	15	2	4	21
South Carolina	4	2	40	5	11	56
Vermont	2	1	7	1	2	10
Virginia	18	12	45	5	12	62
West Virginia	3	1	15	2	4	21
Subtotal	641	258	990	122	278	1,390
North Central						
Illinois	150	73	158	19	44	221
Indiana	30	11	84	10	24	118
Iowa	10	6	26	3	7	36
Kansas	6	3	15	2	4	21
Kentucky	23	18	33	4	9	46
Michigan	67	31	136	16	33	190
Minnesota	24	9	40	5	11	56
Missouri	62	28	52	6	14	72
Nebraska	2	0	7	1	2	10
North Dakota	1	0	2	<1	1	3

TABLE 36. - Mercury Losses from U.S. Paint Manufacturing Operations, by State, 1973
(kilograms)
(continued)

Region and State	Number of Establishments with Less than 20 Employees	Number of Establishments with More than 20 Employees	Mercury Losses to Land	Mercury Losses to Air	Mercury Losses to Water	Mercury Losses to Total
North Central						
Ohio	101	52	172	21	48	241
Oklahoma	15	5	15	2	4	21
South Dakota	1	0	2	<1	1	3
Tennessee	19	7	55	7	15	77
Wisconsin	31	9	62	8	17	87
Subtotal	542	252	859	104	239	1,202
South						
Alabama	14	6	40	5	11	56
Arkansas	8	2	22	3	6	31
Louisiana	9	3	22	3	6	31
Mississippi	6	2	22	3	6	31
New Mexico	2	0	2	<1	1	3
Texas	89	42	91	11	26	128
Subtotal	128	55	199	25	56	280
Mountain						
Colorado	12	5	15	2	4	21
Idaho	5	2	7	1	2	10
Montana	2	0	2	<1	1	3
Utah	5	3	7	1	2	10
Wyoming	1	1	2	<1	1	3
Subtotal	25	11	33	4	10	47
West						
Alaska	0	0	0	0	0	0
Arizona	2	1	9	1	3	13
California	217	90	191	23	53	267
Hawaii	1	0	0	0	0	0
Nevada	2	0	2	<1	1	3

TABLE 36. - Mercury Losses from U.S. Paint Manufacturing Operations, by State, 1973
(kilograms)
(continued)

	Number of Establishments with		Mercury Losses			
Region and State	Less than 20 Employees	More than 20 Employees	Land	Air	Water	Total
West						
Oregon	16	9	17	2	5	25
Washington	25	11	33	4	9	46
Subtotal	263	111	252	30	71	353
Total	1,599	687	2,333	285	654	3,272

Source: Derived by URS from 1973 Census of Manufacturers.

proportion to population across the United States. Analysis of the table indicates that 42 percent of the mercury losses in paint manufacture occurred in the Atlantic region, 37 percent in the North Central region, 9 percent in the South, 1 percent in the Mountain region, and 11 percent in the West.

The U.S. paint industry has a large number of small "mom and pop" manufacturers (less than 7,000 gallons per day). However, the larger manufacturers account for the majority of production. Establishments with an average of 19 or less employees account for only about 8 percent of the value of shipments added by manufacture, even though such plants comprise 70 percent of all manufacturing establishments.

In 1973 more than 180 million gallons of exterior paint (98 million gallons of latex and 82 million gallons of oil/alkyd) and 160 million gallons of interior latex paint were manufactured by the paint industry.* The industry is expected to grow at a 5-percent annual rate through 1983. On this basis, 178 million gallons of exterior paint and 211 million gallons of interior paint will be formulated and sold in 1983.

1973 Technology. Figure 41 is a flow diagram showing mercury losses during typical paint manufacturing operations. The principal loss occurs during formulation when the ingredients are mixed in large metal vessels. (The size of these vessels varies from a few hundred to several thousand gallons.) Two types of losses occur during the process--bad batch losses and losses due to cleaning of the vessels. Industry representatives indicate that upwards of 3 percent of product is lost during formulation. However, we estimate (conservatively) that only 1.2 percent of the product contains mercury. (This lower level of loss was selected because phenylmercuric compounds, which are very expensive compared to the other paint ingredients, are added in the later steps of paint formulation; therefore most of the bad batches will have been detected before the phenylmercuric compounds are added.)

The largest share of the manufacturing loss of mercury (some 71 percent of total manufacturing losses) is to land. Most of this type of loss is from the

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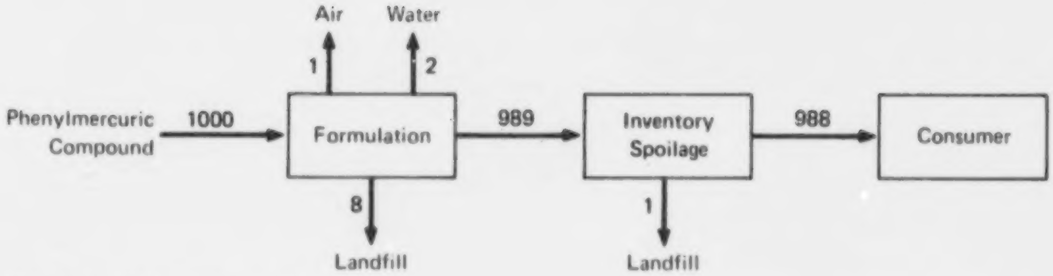
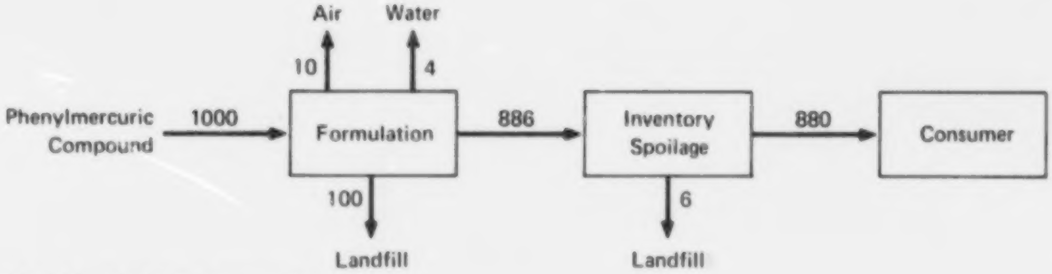
* Interior oil-based paints are not included because they contain relatively little mercury.


Air
Water
1
2
Phenylmercuric Compound
1000
Formulation
989
Inventory Spoilage
988
Consumer
8
1
Landfill
Landfill

SOURCE: URS Research Company.

Figure 41 FLOW DIAGRAM OF ESTIMATED MERCURY LOSSES IN TYPICAL PAINT MANUFACTURING OPERATIONS IN 1973 (for manufacture of 250,000 gallons of latex paint)


Air
Water
10
4
Phenylmercuric Compound
1000
Formulation
886
Inventory Spoilage
880
Consumer
100
6
Landfill
Landfill

SOURCE: URS Research Company.

Figure 42 FLOW DIAGRAM OF ESTIMATED MERCURY LOSSES FROM TYPICAL PAINT MANUFACTURING OPERATIONS IN 1983 (for manufacture of 250,000 gallons of latex paint)

settled solids collected from bad batches and vessel washwater. Other losses to land are from inventory spoilage, spillage, and discarded washwater filters. These solids are generally disposed of in nearby landfill sites.

Approximately 20 percent of paint manufacturing mercury losses are to water. Most washwater and bad batch water is allowed to settle (to remove solids) and is then filtered (for more solids removal) and discharged into the sewer system. Phenylmercuric acetate, the mercury additive used most in paint, is slightly soluble. Phenylmercuric oleate, however, is nonsoluble in water. Cumulatively, the most significant offenders in water discharges are the small "mom and pop" manufacturers, who tend to flush waste down sewers rather than collecting the solids for proper disposal. Mercury dissolved in solvents is generally not a major problem, because most manufacturers store these waste liquids in 55-gallon drums for recycling back to solvent distributors. Except in very large plants (80,000 gallons of paint per day) it is not economically feasible to recycle washwater for use in subsequent batches.

The remaining 9 percent of the manufacturing loss is to air. These losses are brought about by volatilization of mercury from water, paint formulation, spillages, etc.

Final consumption accounts for the major loss of the mercury used in paint. Of the 7,571 flasks used as water-based paint additives in 1973, an estimated 65 percent of the mercury was emitted, probably as phenylmercuric acetate or similar compound, to air. Minor quantitities were discharged to water (via sewers) and to landfills; the balance remained in the applied paint. Estimated losses to air after paint application are 3.8 to 4.0 $\mu g/m^3$ immediately after painting, 1.3 to 1.7 $\mu g/m^3$ up to 200 hours after painting, and 0.07 $\mu g/m^3$ after three years (Ref. 80). Mercury emissions from latex paint have been observed to occur seven years after application; the rate of emission is proportional to temperature increases. Losses to land occur when paint is spilled in the soil, or when paper, rags, cans, and brushes are discarded, or when old, partially used paint is thrown away. Losses to water occur when paint brushes and cans are cleaned; these residues are flushed directly into sewer systems.

1983 Technology. Figure 42 is a flow diagram of estimated mercury losses during paint manufacture in 1983. It is assumed that the 1983 technology is essentially the same as the 1973 technology, but that paint manufacturers will add flocculents to washwater to settle out dissolved mercury. This residue, along with other solids, will be disposed of in nearby sanitary landfills. It is estimated that in total, the manufacturing mercury losses will be about 89 percent to landfill, 8 percent to air, and 3 percent to water.

It must be noted here that the EPA is considering the complete curtailment of all mercury pesticide use in the United States. If this occurs, mercury will no longer be used by the paint industry in 1983, and Figure 42, of course, would not apply.

Table 37 compares estimated losses of mercury from paint manufacturing and consumer use for 1973 and 1983. The "low technology" level shown in the table would occur if the paint industry grows at an annual rate of 5 percent and mercury usage decreases by 50 percent. If this situation did indeed materialize, the use of mercury would remain stable at approximately 7,600 flasks annually.

Alternative Technologies. Very little mercury is discharged during paint manufacture (1.2 percent of the mercury consumed), but substantial discharges to the environment occur when consumers use the paint. If these losses cannot be tolerated in the future, less toxic or nontoxic additives will have to be substituted for mercury.

Many nonmercury substitutes are currently being used by manufacturers; the more promising substitutes contain tin, copper, or boron. Some of the additives that are considered less toxic than mercury are tributyl tin oxide (or esters), triaryl bismuth, triaryl boron, cuprous oxide, copper 8-hydroxyquinalinalate, zinc chromate, and metal chelates of acetoacetic ester (Ref. 77). However, many paint representatives are not completely satisfied with mercury substitutes. The disadvantages cited include: substantially higher cost; higher concentrations required (1 to 2 percent by paint weight); substitutes are not as effective in preserving paint in the can; paint properties are sacrificed (pigment discoloration, viscosity changes, bad odors, fluorescence, etc.); substitutes are not as effective in preventing mildew growth on painted surfaces; and sufficient field testing has not been done. Another problem in finding a quick pesticide substitute for mercury is that the product should have no adverse long-term environmental properties. However, it should be

TABLE 37. - Estimated Mercury Losses
from Paint Manufacture and Use
1973 and 1983
(kilograms)

Losses to	1973 Losses from		1983 Losses from	
	Manufacturing	Consumer Use	Manufacturing	Consumer Use
Land	2,333	8,140	2,890	8,140
Air	285	173,610	285	173,610
Water	654	1,000	97	1,000
Total	3,272	182,750	3,272	182,750

Source: URS Research Company

noted that most paint manufacturers recognize that effective substitutes will be developed and are actively--even though reluctantly--looking for them.

Most states have ignored the use of mercury in paint, although these same states generally have stringent limits on the use of mercurial pesticides. According to Ref. 146, only Connecticut has an outright ban on the use of mercurials in paint (however, this ban is not being rigorously enforced). In New York all mercurial pesticides are banned, except those in paint. In Illinois all manufacturers who use 15 or more pounds of mercury product per year must register with the Air Pollution Board; also, discharges to water must not exceed 1 ppb. However, neither of these constraints is an outright ban and mercurial-containing paints continue to be manufactured (by obtaining exceptions to discharge criteria) and used in Illinois. In general it appears that the use of mercurials in paint is either ignored or discouraged. But, coupled with the action of the federal government, the manufacturers themselves have moved to switch to nonmercurials in expectation of increasingly stringent regulations. But as discussed elsewhere, manufacturers have had problems in using the substitute additives, and as a result the state has already allowed a number of exceptions. Texas also has discharge requirements on the release of mercury to water which are not as stringent as those in Illinois. No adverse impact on paint manufacturers in Texas has been reported, possibly because of nonenforcement of the law.

Sector VIII - Commercial Final Consumption

Agricultural Pesticides

Agricultural use of pesticides for seed dressing is based on the necessary control of about 1,100 disease-producing (pathogenic) and 95 discoloring organisms found in or on seed (Ref. 2). Of all chemicals developed in the last 50 years, none possess as broad a spectrum of fungicidal activity as do the mercurials. Organomercurial dressing of wheat, barley, oat, and rye seed is generally recognized as a factor contributing to increased cereal grain production throughout the world. Though effective substitutes exist for all antipathogenic functions of the organomercurials, the mercurials are effective at considerably lower concentrations (Ref. 81) and therefore cost less than most (if not all) alternatives.

After the 1970 USDA ban on all alkylmercury pesticides, phenylmercuric acetate (PMA) emerged as the dominant organomercurial used in agriculture. Though PMA does not have the antifungicidal range of the alkylmercurials, it is demonstrably less persistent and less toxic to terrestrial and aquatic life, and it has efficiency advantages over substitute compounds in many limited seed treatment applications. Nonetheless, awareness of the environmental factors involved, together with the development of viable alternatives, has led to a significant decrease in use of mercurial chemicals in agriculture. Even before the 1970 ban the agricultural use of mercury was lessening--it declined 10 percent in 1968, 20 percent in 1969, and 33 percent in 1970 (Ref. 35). Mercury use in 1971 was only one-third as much as in 1966 (Ref. 83). The 1970 suspension of alkylmercurials and the probability of additional action against the remaining organomercurials have accelerated this trend. In 1973 usage was only about 21 tons* and an even lower tonnage is expected in 1975.

PMA is manufactured almost exclusively in the New Jersey region, and most of the PMA for seed treatment is ultimately dispersed throughout the major wheat and barley producing states in the Midwest. According to the URS national inventory, the largest mercurial pesticide users in 1973 were North Dakota, Kansas, Montana, and Oklahoma.

At present, PMA and all other mercurial pesticides are under cancellation by EPA. These compounds can be distributed, however, until the EPA administrator officially suspends them, providing that evidence presented at the pesticide hearings in Washington does not warrant reversal of the cancellation. Whatever the result, the cancellation has had a marked effect upon the mercurials. Manufacturers have dropped most of their mercury registrations and dealers have curtailed their supplies to avoid holding quantities of "inevitably restricted" material.

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* URS reapportionment of Bureau of Mines" statistics.

As more efficient and less expensive compounds are developed, and as the mercurial threat to the environment is more clearly demonstrated, usage will decline with or without the ban. By 1983, this usage could be less than 9 tons annually, even without further EPA restrictions.

The Bureau of Mines predicts a 75.8-ton annual "agricultural" use by 1985 without any further EPA restrictions (Ref. 14). When the URS 70/30 nonagricultural/agricultural ratio is applied to the 75.8-ton estimate (which includes both agricultural and nonagricultural mercury biocides), a 1985 forecast of about 23 tons for seed treatment is established. The URS 10-ton forecast for 1983 is based primarily on the current downward trend in agricultural seed treatment use of the mercurials. Because of the efficiency and economics of mercuric pesticides use, that trend would gradually be reversed, unless there is an EPA suspension. Thus, consumption can be expected to exceed 9 tons and to approach 23 tons after 1983.

Assuming a further EPA action against the mercurials, the Bureau of Mines estimates a probable usage of 17 tons and a low of 10.3 tons for all mercuric pesticides. These figures are based on continued utilization in some applications under strict governmental control, almost exclusively for industrial purposes where foodstuffs are not involved. Thus, there will probably be no consumption for seed treatment by 1983, if the 1975-1976 EPA suspension materializes.

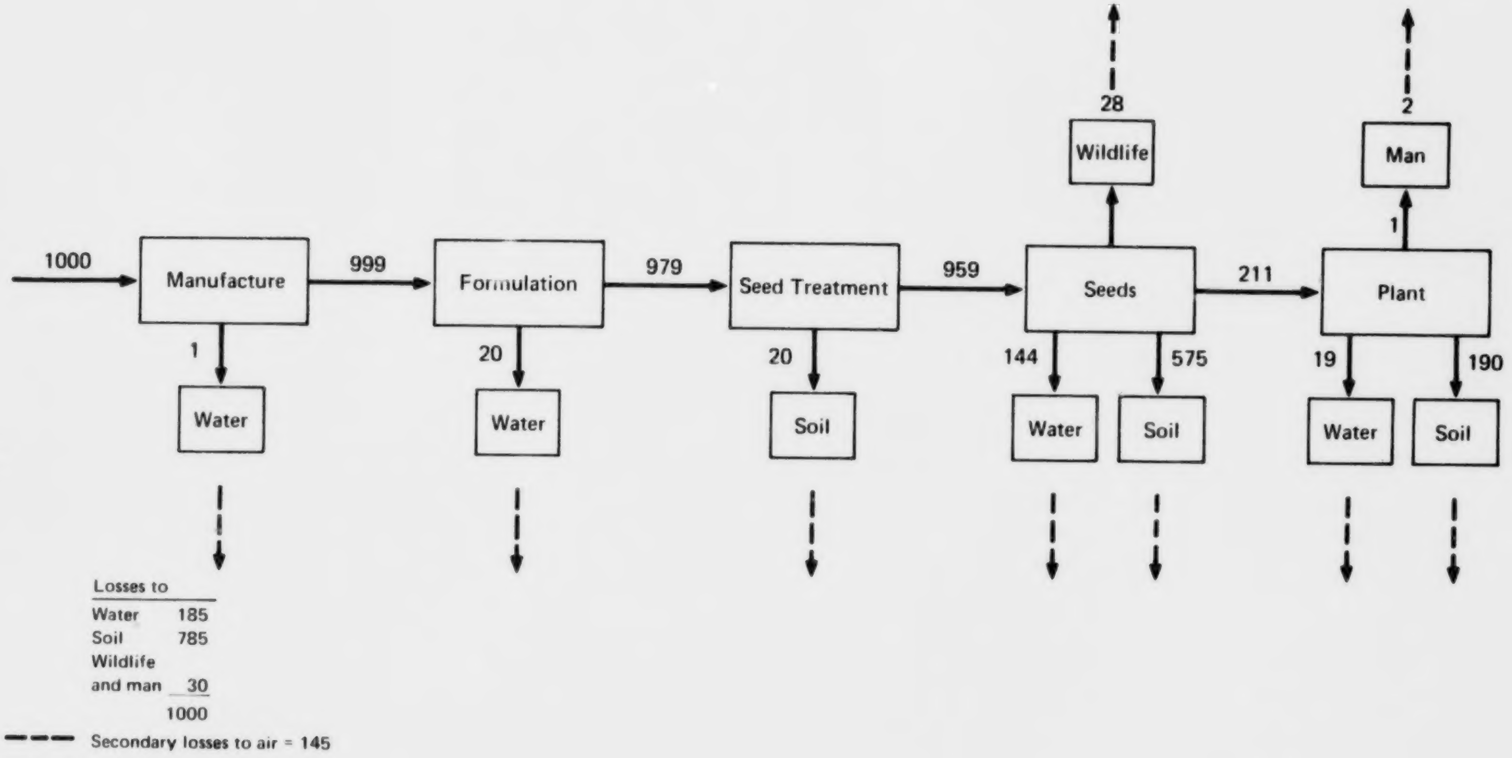
Because there is a large supply of organomercurials, elimination of these pesticides from agriculture will not be abrupt. The least damaging means of disposing of them would be through the standard treatment of wheat and barley seeds. Draw-down of the organomercurial stores could take several years, but by 1983 mercurial pesticide usage in agriculture would be effectively zero, if there is an all-inclusive EPA suspension.

The beneficial and detrimental factors associated with the seed treatment are more thoroughly discussed in the following references:

Ref. No.	
2	Overview of mercuric pesticide usage--especially translocation in plants and bioaccumulation
84	Technical summary of chemical form, method of application and fate of the organomercurials in agriculture
85	Translocation and bioaccumulation
86	Efficacy, application, bioaccumulation, and results of the methylmercury ban in Sweden
81	Relative effectiveness of PMA

1973 Technology. The path and fate of mercury in agricultural pesticide usage are diagrammed in Figure 43. The manufacture and formulation of mercuric pesticide compounds (principally PMA) result in a limited loss to water. In the figure, the 98-percent efficiency value assigned to formulation represents a worst-case situation. Development of new processes in the last 20 years which are responsive to the properties of the chemicals used has made the seed treatment process extremely efficient. The 2-percent loss to soil is attributable to cleansing of the seed-treater (a "mistomatic" when PMA is used), disposal of PMA-30 containers, and washing of trucks used to transport treated seed.

Most of the mercury lost to the environment is lost after the seed is planted. Depending on the chemical composition of the pesticide used, and thus on differing affinities for individual components of the soil, a portion of the organomercurial compound on the seed will be leached out of the soil and lost to water. The phenylmercurials are not immobilized in the upper few inches of soil as are the alkylmercurials. Consequently, the phenylmercurials penetrate


1000
Manufacture
1
Water
999
Formulation
20
Water
979
Seed Treatment
20
Soil
959
Seeds
28
Wildlife
144
Water
575
Soil
211
Plant
1
Man
2
19
Water
190
Soil
Losses to
Water 185
Soil 785
Wildlife
and man 30
1000
Secondary losses to air = 145

SOURCE: URS Research Company.

Figure 43 MERCURY BALANCE, AGRICULTURAL PESTICIDE MANUFACTURE AND USE, 1973 TECHNOLOGY

deeper into the surface and can be leached more readily. Approximately 22 percent of the mercury on the seed is incorporated in the plant tissue, though only 1 percent of that quantity is ultimately translocated into the edible grain portion (Ref. 85). More significant translocation occurs after foliar application of mercuric pesticides to control a wide range of fruit and vegetable pests (residues in crops four to six times higher than unsprayed controls; Ref. 2). Recognition of the environmental factors involved led to an EPA suspension of PMA as a foliar crop spray. Thus, the use of mercury compounds for this purpose is assumed to have disappeared by 1973.

Despite leaching, translocation, and loss to seed-eating birds, more than half of the mercury on the treated seed remains in the soil. In addition, most of the mercury transferred to the plant is plowed under after harvest and returns to the soil via decomposition. Overall, more than 80 percent of all mercurials used for agriculture in 1973 were incorporated in the soil.

Not all the mercury lost to the soil or to water remains there indefinitely. Approximately 15 percent of the mercury in the soil is lost as volatile mercury vapor to air each year (Ref. 90). A comparable loss figure is postulated for mercury in water. Similarly, the quantities of mercury assigned to wildlife and man in Figure 43 do not connote the ultimate fate of the mercury. Most of the mercury entering the biological food chain is lost as waste, with the persistence of the phenylmercurials substantially below that of the alkylmercuric compounds commonly regarded as hazardous to aquatic and terrestrial life.

1983 Technology. Without a mercuric pesticide ban, a flow sheet for 1983 would reflect 1973 types and percentage losses. Because agricultural pesticides are produced expressly to be applied to the environment, little can be done to control mercury dispersion through that environment short of restricting the initial application. Control of mercury loss during formulation and seed treatment would be counterproductive, in view of the negligible loss and the high payoff in increased yields. The only major difference between the 1973 and 1983 technologies would be in the initial quantities of mercuric pesticides entering the system. As mentioned previously, it is likely that the 1983 figure will be less than half of the 1973 consumption.

Alternative Technologies. The EPA contends that there are viable alternatives to organomercurial seed treatment for disease control. In most seed treatment applications, the American farmer has switched to substitute compounds. These substitutes and effective combinations thereof are registered with the EPA (FIFRA Docket No. 246 et al., USEPA, before the Administrator: Notice of Substitutes for Mercurial Seed Treatment, 1975). Unfortunately, the safety of many of the alternative compounds presently used in agriculture remains in question (Ref. 15). A growing number of farmers have also opted to plant untreated seeds in recent years and, as a result, reports of unharvested acres due to a variety of diseases (e.g., smut) that are normally controlled by seed treatment have increased. As more effective alternatives are developed and produced and as these alternatives gain acceptance, the loss in cereal grain yield will be diminished and/or eliminated. Until the efficacy and quantities of substitutes required match the efficiency of the mercurials, though, there will be increased costs to the commercial seed treater (e.g., machine replacement), the farmer (e.g., mercuric pesticide/substitute price difference), and the consumer. The cost of mercury substitutes for seed treatment can range from a savings of $1 million to a $15 million increase (for 108 million acres of grain, assuming 50 percent treated seed). Costs to consumers are estimated at 10 cents per capita per year.*

Most, if not all, of the problems with mercuric pesticides in agriculture have been a result of improper use of, or accidental exposure to, alkylmercury-treated grain. Undeniably, methylmercury in seed dressings did represent a direct hazard to wildlife and an indirect hazard to man. Comparable problems with the other organomercurials (PMA) are feared. The EPA contends that the risk associated with the use of mercurial pesticides outweighs any benefit of such use and that the existence of preferable alternatives mandates mercuric pesticide removal. For most uses of the mercurials, such a contention is realistic, but so far not all available alternatives are "preferred" by the farmer. Farmers sold on the efficiency of mercury treatment contend that, until the economic and efficacy gap between the mercurials and best substitutes is closed for all seed treatment applications, a governmentally supervised

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* Hertzmark (1974), as quoted in Ref. 15.

"limited use" approach might be more productive, in view of the world food shortage. At the International Congress on Mercury (1974), L. J. Goldwater summarized the basis for this contention:

> "More than twenty years devoted to studying the effects of phenylmercurials on humans had convinced me that these compounds, when properly used, present no hazard to the user nor to the environment. In agriculture the phenyls can replace the alkyls in protecting seed before germination and in controlling a number of plant diseases caused by fungi. I am not an expert in plant pathology, but I am told by competent authorities that the phenylmercurials cannot be matched by other fungicides and that their use adds substantially to yields of food and fibre. Senseless and unnecessary curtailment of the use of these valuable chemicals resulting in decreased production and consequent increase in prices would be one more victory for the anti-mercurialists."

Nonagricultural Pesticides

In 1973, larger quantities of mercury-bound fungicides were used for nonagricultural turf treatment than for agricultural seed treatment. The nonagricultural/agricultural (70/30 percent) pesticide breakdown in the URS national inventory reflects the ubiquity and frequency of nonagricultural use. Mercurial fungicide treatment of turf is practiced throughout the United States and requires a continued series of applications to be effective. The cost, range, and effectiveness of the mercurials have led to their widespread use as turf fungicides. In addition mercury-containing pesticides have a limited application to control Dutch elm disease. Except in paint, other nonagricultural uses of mercuric pesticides (e.g., as wood preservatives) are assumed to have declined to insignificant proportions by 1973.

Parasitic fungi are the major disease-causing agents that are effectively controlled by mercuric compounds. The mercurials act as protective-contact fungicides. Application to seed, foliage, or soil can provide a surface shield against fungus spores. Foliar spraying, which treats the turf soil indirectly, is the principal means of application; treatment of grass seed is extremely rare. Commercial turf operations depend heavily upon the organomercurials.

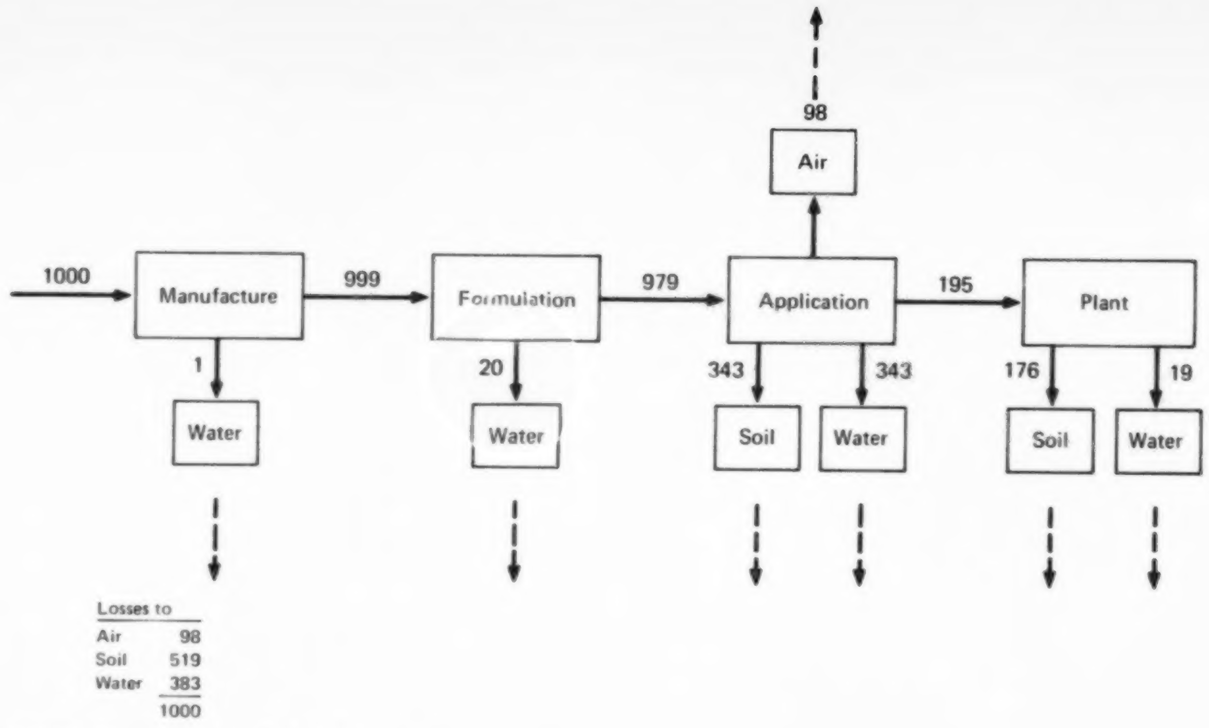
Golf courses, parks, cemeteries, and lawns historically have received most of the nonagricultural inorganic and/or organic mercury fungicide treatment. By 1973, only golf course greens, tees, and fairways were still receiving significant amounts of mercury.

The 1970 alkylmercury ban, the current mercuric pesticide cancellation, and the rapid emergence of substitute compounds have reduced the nonagricultural use of mercury-based fungicides. Recognition of mercury accumulation in the fish in golf course lakes due to runoff and percolation, coupled with a general concern about the hazards of mercury's entrance into the biological food web, has accelerated the abandonment of these chemicals.

The 1973 figure of 44.0 tons of mercurial fungicides assigned to nonagricultural use is considerably below the consumption averages of the 1960s. User dependence upon these fungicides will decrease still further during the next few years as major producers continue their cutbacks but, without an EPA ban, it is likely that this use will stabilize at a level only slightly below the 1973 total. Nonagricultural turf treatment with the mercurials probably will not decrease as much as agricultural seed treatment, principally because (1) the nonagricultural threat to man and the environment is not as direct, (2) considerably more money is invested in the turf industry, and (3) the activity range of the alternatives has not yet been as thoroughly proven as have the seed-treatment alternatives. The Bureau of Mines (Ref. 14) forecasts a high of 53.1 tons of mercurial fungicides for 1985.

If a suspension is imposed, usage will definitely diminish, but not all organomercurials may disappear immediately. Use of stored mercurials to combat severe disease problems will continue at least through the 1970s. Though alkylmercurials were banned in 1970, these stored mercury compounds are still used occasionally in 1975. As mentioned previously, gradual use of the organomercurial stores in this manner is the least damaging method of removal. The Bureau of Mines does not expect a complete elimination of all nonagricultural uses of mercuric pesticides and consequently predicts a probable consumption of 14 tons per year for limited nonfoodstuff applications.

1973 Technology. Figure 44 shows the movement of mercury into the environment as a result of nonagricultural pesticide uses. Because other pesticide


1000
Manufacture
999
Formulation
979
Application
195
Plant
1
Water
20
Water
343
Soil
343
Water
176
Soil
19
Water
Air
98

Losses to	
Air	98
Soil	519
Water	383
	1000

– – – Secondary losses to air = 135

SOURCE: URS Research Company.

Figure 44 MERCURY BALANCE, NONAGRICULTURAL PESTICIDE MANUFACTURE AND USE, 1973 TECHNOLOGY

sources contribute a relatively insignificant amount of mercury to the environment, the figure shows only the mercury lost in turf treatment. Manufacture and formulation of the inorganic and organic (PMA) chemicals required for turf application parallel the agricultural loss figures. After formulation, though, the similarities between agricultural and nonagricultural usage end.

As the inorganic and organic fungicides are applied, a portion of the mercury is lost in aerosol form directly to air during the spraying process. Similarly, mercury is lost to air as volatile mercury vapor during the weeks following application. The total amount lost to air depends on climatic conditions during application and on the chemical form of the fungicide. The URS 10-percent estimate used in Figure 44 represents a maximum average loss to air.

Uptake of mercury by plants treated with protective-contact materials is much less than plant absorption of the systemics. Though as much as 50-percent absorption of PMA has been reported following foliar application to rice plants (Ref. 2), a 20-percent figure is more realistic for grasses, considering their morphology and the limited residence time of the pesticide on their surface due to runoff loss. Most of the 20 percent may actually remain at the base of the grass blade or in the upper portion of the turf mat. Nonetheless, even significantly reduced levels of the pesticide spray on the plant's surface can afford effective protection. Repeated applications ensure the continued presence of adequate pesticide residues.

The key aspect of Figure 44 is the amount of mercury lost to water (approximately 40 percent). The initial presence of the pesticide on exposed surfaces, the high frequency of watering, and the unusual configuration of golf course terrain combine to make mercury-loaded surface runoff a significant factor. Results from a University of Missouri study on golf course lake contamination indicate significant pollution of the lakes due to greens treatment (Ref. 91). A portion of the mercury not immediately carried to the water environment moves down through the soil. A fraction of this mercury will, in turn, be leached from the soil and enter the groundwater system. Leaching from the soil is substantially increased when organically bound mercury is used in the treatment. Inorganic mercury tends to be more efficiently bound by the soil and to remain in the top few inches of earth. Because of these factors that encourage mercury movement into the water, equal and significant loss to land and water during and immediately following application is postulated.

The overall loss to soil (> 50 percent) exceeds the mercury loss to water (< 40 percent) because most of the mercury tied to turfgrass is mowed and removed every few weeks. The grass cuttings are either returned to the soil as mulch or dumped. Approximately 10 percent of the mercury associated with the cuttings is leached from the soil during and after decomposition.

Though there is no direct consumption of mercury by man, there is evidence that a portion of the mercury which enters the water environment is eventually accumulated in the aquatic food web of golf course streams and lakes. The type and extent of such bioaccumulation are not significant enough to threaten man but, if preventive measures are needed, they are readily available (e.g., prohibition of fishing in such lakes and streams).

1983 Technology. No changes in the ultimate fate pattern of nonagricultural pesticides are expected by 1983. As previously stated, initial amounts of mercuric pesticides used for turfgrass treatment may be slightly lower by 1983, but control of the mercury as it is dispersed through the environment is not possible, due to the general nature of pesticide use.

Alternative Technologies. Successful growth and upkeep of disease-free turfs depend more upon organomercurial availability than do growth and upkeep of cereal grains. Nonetheless, alternatives for turfgrass fungicides do exist and are being used throughout the country (FIFRA Docket No. 246, et al., USEPA, before the Administrator: Notice of Substitutes for Mercurial Turfgrass Fungicides). Unfortunately, the economic burden and doubts concerning efficacy of these alternatives hinder their complete acceptance. Though no health problems have been attributable to turfgrass use of mercuric pesticides, the EPA position on mercury use for nonagricultural purposes is consistent with its position regarding agricultural seed treatment: the risks associated with the use of mercurial pesticides outweigh any benefit of such use, and the existence of preferable alternatives mandates mercuric pesticide removal.

Laboratory Uses

Metallic mercury and mercurial compounds are used for many laboratory purposes. They are standard laboratory items as reagents and indicators, for calibration and sealing, and in vacuum pumps (Ref. 68). Mercury is used primarily for radioactive diagnosis and as a fixative for tissues in hospitals. According to Ref. 68, radioactive mercury is available for brain scanning for tumors and for renal scanning. Mercuric chloride has been used in the prevention of suture line recurrences in anterior resections for colonic cancer (Ref. 68).

University and high school chemistry laboratories use mercury in class experiments and independent research projects. Due to a growing awareness of the potential adverse effects of mercury flow into the natural environment, research into the chemical properties and toxicity of mercury apparently has increased during the last decade. Use of mercury compounds in university and high school chemistry programs, however, is generally acknowledged to be decreasing.

According to Ref. 12, 22,680 kg of mercury were consumed in U.S. laboratories in 1973. This tonnage was considerably below the 1971 use (62,325 kg) and about one-half the 1965-1968 average annual consumption of 43,546 kg (Ref. 43). The marked consumption decrease between 1971 (62,325 kg) and 1972 (20,503 kg) is not explained by any governmental restrictions or variations in method of accounting. Significant fluctuations, though not of this magnitude, were evident in other years. The general decline in consumption in the last ten years probably reflects a more conservative approach to mercury use in the laboratory and more efficient recycling of the mercury that is used.

Current laboratory uses for mercury will not diminish markedly by 1983. Consumption will decline gradually as efforts to recover and recycle mercury efficiently are accelerated. This decline may be countered, however, by increased demands from hospital and research laboratories caused by population growth and expanded research efforts on mercury. Considering all these factors, URS forecasts a 1983 laboratory consumption of approximately 18,000 kg.

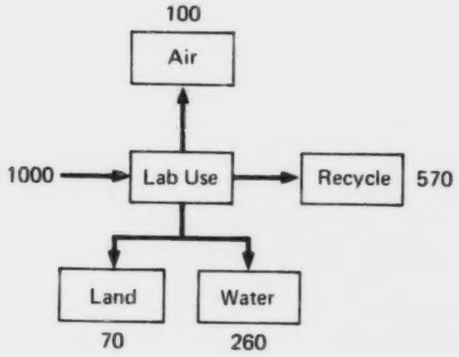
1973 Technology. The flow of mercury into and through the laboratory is diagrammed in Figure 45. The diagram represents a cumulative accounting of the different types of laboratory usage: university and high school, independent research, and hospitals. Thus, the percent loss to a particular medium is indicative of laboratory use in general and not of specific laboratory applications.

Mercury emissions to air resulting from hospital uses probably exceed 10 percent of the mercury consumed in these applications because of the hospital practice of incinerating tissues, bandages, and other used supplies, some of which may contain traces of metallic mercury or a mercuric compound. University and high school laboratories and independent research laboratories probably lose less than 10 percent of their mercury to air. Overall, therefore, the 10-percent loss to the atmosphere assumed in the URS inventory is probably realistic.

Mercury losses to land could occur through the disposal of mercury containers, toweling used to absorb spilled mercury, and defunct vacuum pumps, among other substances. Such losses would tend to be greater for university and high school laboratories, where incineration is not practiced and inexperience with the handling of chemicals is greatest. URS estimates that as much as 7 percent of the mercury used in laboratories may ultimately be lost to land.

Most laboratory mercury that is not recovered and recycled is lost to water. Fixative solutions (mercuric chloride) are commonly flushed down sinks. Antiseptic applications of mercuric compounds in the hospital operating room are also eventually washed away. Accidental spills and the cleansing of laboratory containers and instruments used in mercury experiments also contribute to mercury discharges to water. Extensive precautions against dumping mercury solutions down sinks can prevent the largest potential source of mercury contamination from reaching the water environment. University and high school laboratories, cognizant of the environmental factors involved, are extremely efficient at collecting and recycling most of the mercury they use. However, occasional dumping of residual mercury-containing solutions will continue to occur as long as mercury and mercury derivatives are used in the laboratory.

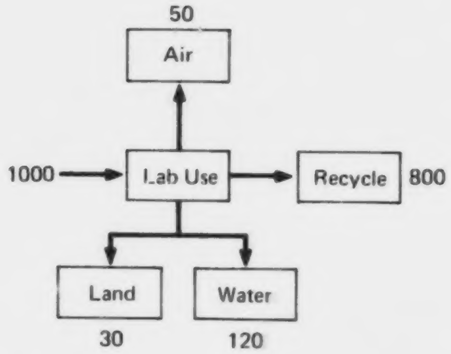
Losses to	
Air	100
Land	70
Water	260
Recycle	570
	1,000


100
Air
1000
Lab Use
Recycle
570
Land
Water
70
260

SOURCE: URS Research Company.

Figure 45 MERCURY LOSSES FROM LABORATORY USAGE, 1973

Losses to	
Air	50
Land	30
Water	120
Recycle	800
	1000


50
Air
1000
Lab Use
Recycle
800
Land
Water
30
120

SOURCE: URS Research Company.

Figure 46 MERCURY LOSSES FROM LABORATORY USAGE, 1983

Laboratory recycling prevents more than half of the incoming mercury stock from being discharged to air, land, or water. University laboratories have achieved an efficient level of mercury recovery through the use of stockroom regulations requiring that fresh mercury be issued only in amounts equal to the mercury being returned. Though initial requests for mercury are filled, control of any additional requests is facilitated by this type of exchange approach. In many instances, individual laboratories in chemistry and biology building are monitored in a similar fashion, though the use of mercury in small research projects is more easily controlled than are miscellaneous and classroom uses.

With the emphasis on recycling during the last decade, the university stockrooms can survive on a "fresh" mercury supply purchased every five to ten years. Thus, for a typical usage of 200 pounds of mercury and its compounds, the individual university laboratory loses 20 to 40 pounds per year (10 to 20 percent). These yearly losses appear in the national inventory only in the years when restocking occurs. The 200 pounds which would appear in those years, however, would not represent the real mercury use, just as zero consumption in the years between restocking does not represent actual mercury use. Therefore, the yearly national consumption total is influenced by the number of laboratories that must replace their mercury stock in that year, and by the amounts needed. The fluctuations in annual laboratory mercury consumption mentioned previously might be partially explained by an uneven distribution of "fresh" mercury requests.

Hospital recycling efficiency is considered to be below that for non-hospital laboratory use. In general, hospital requirements for mercury are more constant and replacement of lost mercury is more frequent than for university and contract research laboratory uses.

After mercury and mercury-containing wastes are collected, they are sent to a chemical recovery center for triple distillation. This process means that ultimate losses are trivial.

1983 Technology. The conclusions reached in Ref. 68 regarding the need and ability to control mercury use in the laboratory are in accordance with the URS findings and fully express the basis upon which Figure 46 was established:

> "Because of the nature of laboratory and hospital operations, there is almost no danger of continuous large effluent flow containing unacceptable concentrations of mercury. The danger is in careless or accidental disposition of relatively small amounts of expended metallic mercury. In a laboratory and hospital context, the best available level of treatment and control consists of conscientious practice of routine methods such as:
>
> (1) Precipitation of dissolved mercury compounds or safe disposal as solid wastes.
>
> (2) Separation of suspended mercury compounds for recovery or safe disposal of solid waste.
>
> (3) Chemical treatment or fixation of spilled metallic mercury before vacuuming or washing, with subsequent precipitation or separation of mercury for recovery or safe disposal as solid waste."

As these practices are more completely incorporated into laboratory operations, the recycle factor will increase and mercury losses to air, land, and water will decrease. Any restrictions placed upon hospital incineration would further increase the 1983 recycle estimate of 80 percent. To achieve 100 percent recycling is not possible because of uncontrollable emissions to air, accidental spills, and user carelessness, which will always characterize the laboratory use of mercury. Nonetheless, mercury losses to air, land and water will probably drop 50 percent or more by 1983 as control measures are increased during the late 1970s and early 1980s.

Alternative Technologies. Alternatives to general laboratory use of mercury either do not exist or are not readily available. Mercury is used sparingly and only in the absence of suitable substitutes. Ref. 68 mentions that nonmercurials might be able to replace particular mercury compounds used as chemical reagents, but no specific examples are cited. Regarding hospital use, Ref. 68 reports that techneitium (^{99m}Tc), radioactive potassium carbonate (^{42}K), and diiodofluorescein (^{131}I) may be used in place of radioactive mercury for brain scans. Centrimide (1-percent solution), which has been shown to be effective in preventing the growth of tumor cells in experimental wounds, could serve as an alternative to mercuric chloride.

An alternative for a specific mercury application in the hospital may be feasible in certain cases and not in others. Thus, any restrictions based on alternative availability and directed toward a particular mercury use would possibly interfere with best medical practice.

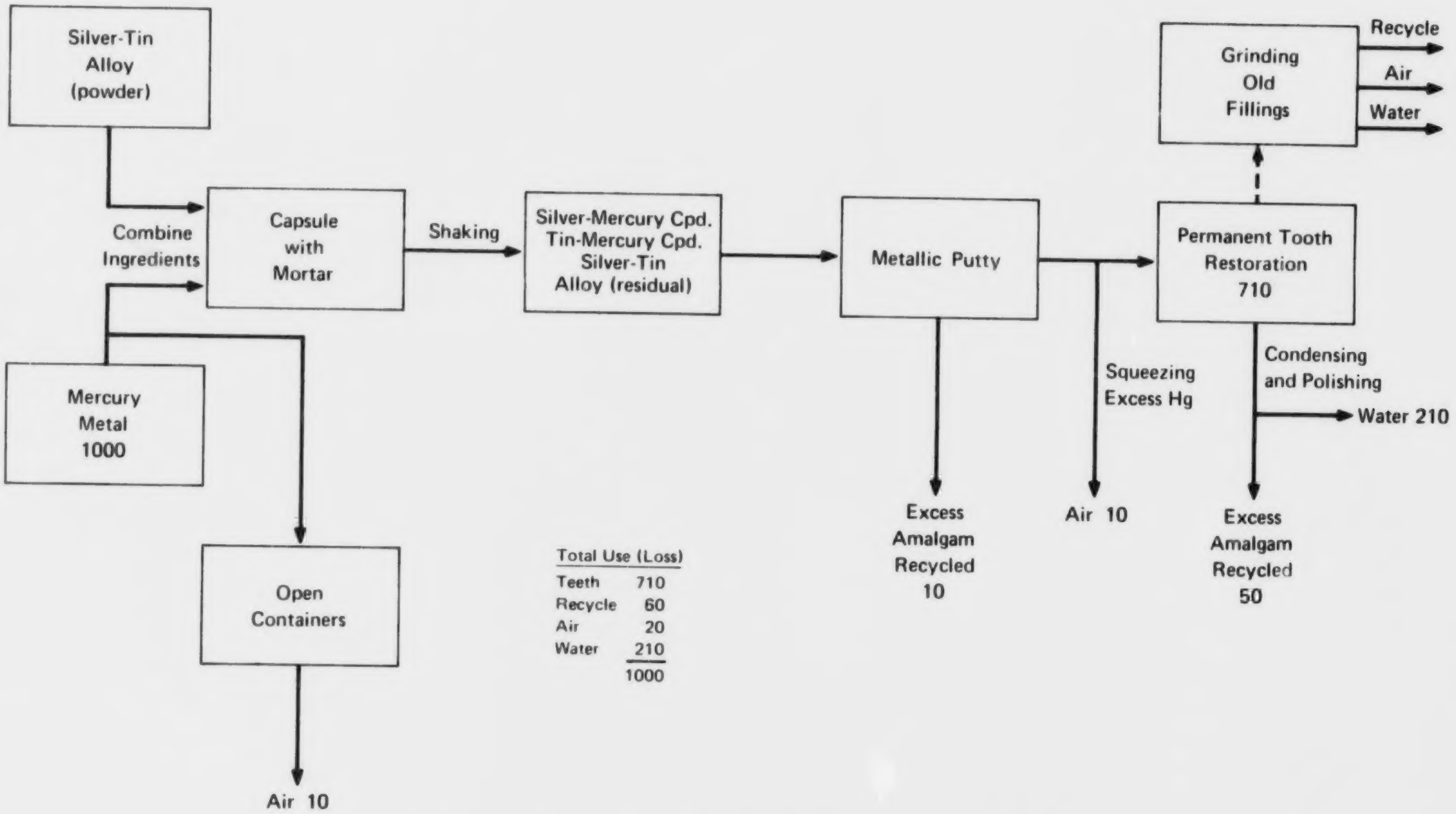
Sector VIII - Personally Oriented Final Consumption

Dental Applications

Mercury has been used as an amalgam in the dental profession since the early 1800s. Historically, this use has been the subject of controversy (Ref. 70), particularly with regard to the potential hazard it poses to the health of the dentist and the patient. Dentists are especially subject to chronic mercury poisoning, because they usually prepare the fillings and thus have the most direct contact with the mercury. Patient contact is limited to a few minutes during amalgam preparation, and only minute quantities are ingested once the restoration is in the teeth. Estimates place the average daily ingestion for people in the United States at 0.2 to 1.5 micrograms (μg) per day per person from dental restorations, based on an average of 0.5 gram per year per person of mercury placed in the teeth and on normal erosion of the restoration (Ref. 92).

The U.S. dental profession's demand for mercury has fluctuated quite erratically over the last 15 years (Refs. 41, 93). Current demand is estimated at roughly 4 percent of total U.S. mercury consumption. Demand for the years to 1983 will probably be tied to population growth; for 1983 a high of 3,600 flasks and a low of 2,100 flasks for dental uses are projected. The most likely value for 1983 is on the high side--approximately 3,500 flasks--because the dental profession is expected to continue using mercury in tooth restorations. However, by 1983, mercury recycling should somewhat slow the net growth rate.

1973 Technology. Figure 47 illustrates the procedure in manufacturing a mercury amalgam for tooth restoration, and indicates the associated losses of mercury at various stages of the process. Restorations are prepared by combining a silver-tin alloy in powdered form with metallic mercury. These ingredients, and a mortar, are placed in a tightly closed capsule mounted on a


Silver-Tin
Alloy
(powder)
Combine
Ingredients
Mercury
Metal
1000
Capsule
with
Mortar
Shaking
Silver-Mercury Cpd.
Tin-Mercury Cpd.
Silver-Tin
Alloy (residual)
Metallic Putty
Excess
Amalgam
Recycled
10
Squeezing
Excess Hg
Air 10
Permanent Tooth
Restoration
710
Grinding
Old
Fillings
Recycle
Air
Water
Condensing
and Polishing
Water 210
Excess
Amalgam
Recycled
50
Open
Containers
Air 10
Total Use (Loss)
Teeth 710
Recycle 60
Air 20
Water 210
1000

SOURCE: URS Research Company.

Figure 47 MERCURY BALANCE, DENTAL APPLICATIONS, 1973 TECHNOLOGY

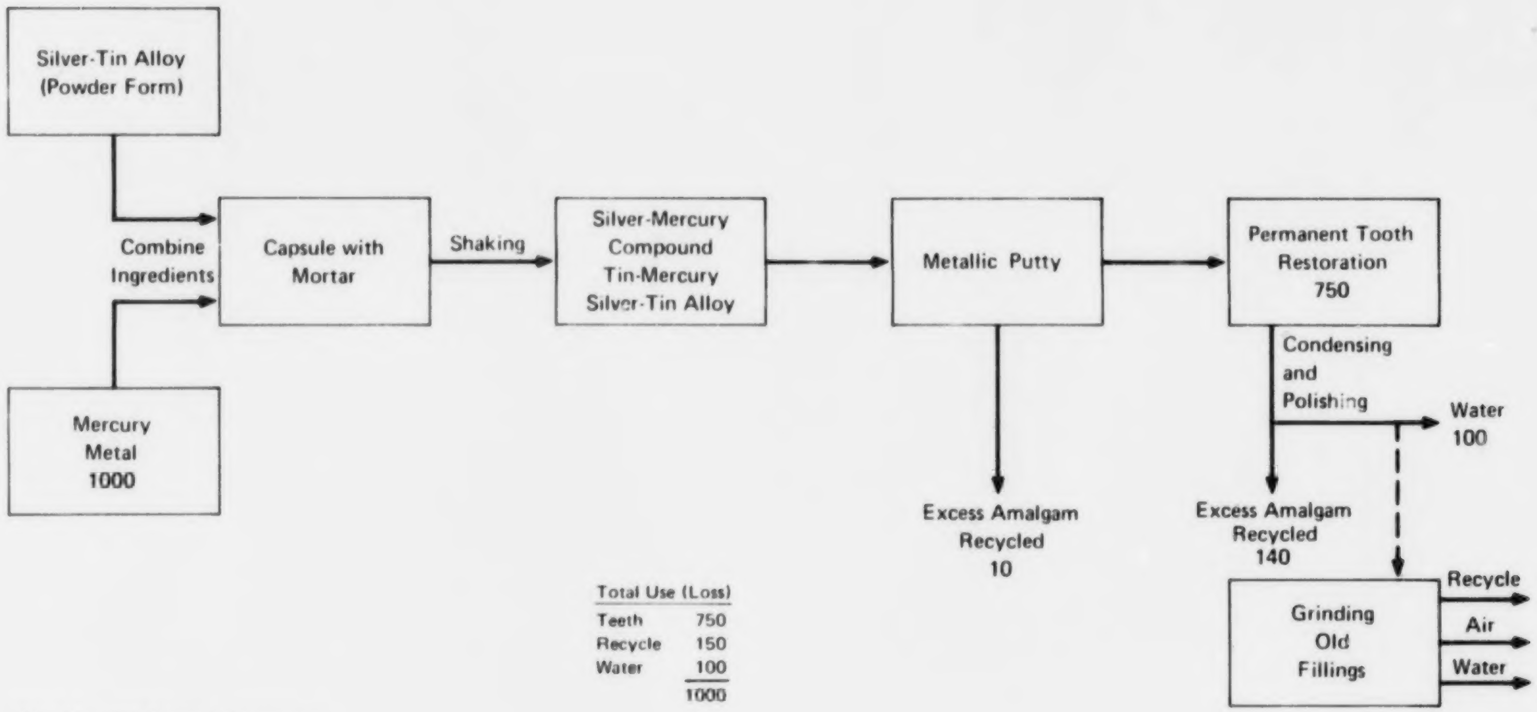
machine which vigorously shakes the ingredients. A metallic putty is formed, composed of silver-mercury and tin-mercury compounds and some residual silver-tin alloy. This putty is then placed in the drilled tooth cavity. The semi-hardened putty is later condensed and polished, and the excess amalgam is removed during the condensing process.

Typically, the mercury is stored in and dispensed from a one- to five-pound container. If the container is improperly sealed or is uncovered, there will be some vaporization. The powder and liquid mercury are mixed in a closed capsule, so no losses occur at this stage. However, after the shaking is complete, the dentist may knead or squeeze out any surplus mercury in the amalgam. If these droplets fall to the floor or onto the work bench, the mercury can become volatilized. Also, when the patient expectorates during shaping of the filling, unless a trap is installed in the plumbing, the excess amalgam and mercury are released into the wastewater system.

1983 Technology. The postulated 1983 technology (Fig. 48) assumes that all dental practitioners are well aware of the potential mercury hazard and have taken all possible steps to reduce mercury loss. "Premixes" are already available in which the metallic mercury and silver-tin alloy can be purchased in measured quantities, so that no open containers of mercury are needed. The mercury is contained in a capsule that, upon shaking, ruptures and permits amalgamation with the alloy. Thus, no mercury need be lost while making the metallic putty.

During installation of the filling, excess amalgam will be trimmed off and must be spit out by the patient. To minimize mercury loss, water basins should be equipped with traps to collect much of the excess amalgam; the mercury so recovered could be recycled.

Mercury can be lost to air and/or water when a filling is removed. Removal is accomplished by drilling through the old filling; small particles of the amalgam are thus emitted to the air and may be inhaled by the patient and dentist. Other bits of the restoration are spit out into the basin. Drilling old fillings is not frequently done, however, as mercury amalgam restorations are intended to stay in place for up to 25 years.


Silver-Tin Alloy (Powder Form)
Mercury Metal 1000
Combine Ingredients
Capsule with Mortar
Shaking
Silver-Mercury Compound Tin-Mercury Silver-Tin Alloy
Metallic Putty
Permanent Tooth Restoration 750
Condensing and Polishing
Water 100
Excess Amalgam Recycled 10
Excess Amalgam Recycled 140
Grinding Old Fillings
Recycle
Air
Water

Total Use (Loss)	
Teeth	750
Recycle	150
Water	100
	1000

SOURCE: URS Research Company.

Figure 48 MERCURY BALANCE, DENTAL APPLICATIONS, 1983 TECHNOLOGY

Alternative Technologies. In terms of actual quantities of mercury lost to the environment, dentistry-associated losses are very small. However, since these losses can occur in confined work and office space, harmful concentrations could build and pose hazards to dentists, technicians, and (less likely) patients. Proper handling techniques and an acute awareness of the potential danger associated with mercury use should mitigate this hazard.

There are a number of ways in which dentists can prevent unusually high mercury concentrations in offices or clinics. The Council on Dental Research sponsored a review of mercury in dental practice which indicated that there will be no hazard to dental personnel or their patients if proper office procedures are followed and scrap amalgam is collected and salvaged. The procedures suggested include storing mercury in unbreakable, sealed containers, confining any inadvertent spills to an easily cleaned tray or similar work area, and working in an uncarpeted area. A drain trap to collect solids should be installed and all amalgam scrap should be collected and stored in a tightly sealed container. Other suggestions include being sure that the area is well ventilated; avoiding heating of mercury or amalgams; using water spray and suction when grinding dental amalgams; coating the restoration surface with a varnish or base; and eliminating the indiscriminate use of mercury-containing solutions.

In sum, careful handling and use of mercury in dental offices are necessary to prevent accidental mercury poisoning, but given present technology, the usefulness of mercury as an amalgam, and the relative ease with which mercury losses can be controlled, it should not be necessary to curtail mercury use in dental restorations. There are, of course, a number of substitutes available for mercury amalgams, although none is as permanent or as economical as mercury. Possible substitutes include silicate/zinc phosphate cements or acrylate and epoxy resins (Ref. 41), as well as gold. None of these is expected to supplant mercury amalgams unless the price of mercury becomes prohibitively high or its use is banned.

Pharmaceuticals

The use of mercury in medicine is a part of the history of man (Ref. 70). Many of the historical applications of mercury have retained a surprising level of popularity and use throughout the 1960s and early 1970s. Organic mercury compounds are used in diuretics and antiseptics; inorganic mercury salts are used in solutions for sterilizing instruments; ammoniated mercury, oxides of mercury, and metallic mercury are used in skin preparations; and phenylmercury compounds are used as preservatives in cosmetics and soaps (Ref. 68). The antimicrobial properties of mercurials make these compounds desirable components of drug, cosmetic, and soap base emulsions, while the fast action and effectiveness of the mercurial diuretics have contributed to their survival. Phenylmercuric acetate is used as a contraceptive jelly.

The pharmaceutical industry used some 20,900 kg of mercury in 1973 (Ref. 37). This level of usage reflects a return to a declining trend in mercury consumption that characterized this industry between 1950 and 1973 (from 207,000 kg in 1950 to 20,900 kg in 1973). The decline is primarily due to the discovery and effectiveness of nonmercurial substitutes, but the toxicity of mercury compounds has also contributed to the marked decrease in their use. In general, mercury compounds have been replaced by drugs which are safer (fewer side effects) and/or as effective as the mercurials. Drugs more specific in their activity are available in many cases.

Mercury-containing pharmaceuticals are produced chiefly in New Jersey. The U.S. market for mercurials as antiseptics has generally followed population growth. As long as mercurial antiseptics are available to the public, there will probably be a constant demand for them, at least through 1983. Mercurial diuretics probably will be maintained as a last-resort alternative to nonmercurial diuretics; thus their use will not decline to zero. However, mercury use in skin preparations and preservatives will almost vanish by 1985 (Ref. 14).

Cammarota predicts a consumption high of about 27,000 kg of mercury for pharmaceuticals in 1985 and a low of about 14,000 kg (Ref. 14). The high forecast is based on expected population growth, and the low forecast is based on elimination of mercurials in the pharmaceutical industry except for special uses for which there is no substitute. A probable consumption level would be about 17,000 kg; this is contingent upon trends in pharmaceutical applications and the possible development of new uses for mercury. This consumption level would be slightly below the present pharmaceutical mercury use of 20,900 kg.

1973 Technology. Figure 49 shows estimated (relative) mercury usage for pharmaceutical applications and corresponding losses to air, land, and water. The loss attributable to production of mercury pharmaceuticals* is limited to residue amounts not exceeding 0.1 percent of the quantity of mercury used in the end product (Ref. 68). These residues are disposed of using a state-approved system of dry-fill burial. Groundwater contamination from the buried mercury residues is assumed to be negligible.

The use figures in Figure 49 approximate the 1968 marketing research findings of the Panel on Mercury of the National Materials Advisory Board of the National Research Council for 1968 (Refs. 94, 95). The losses assigned to each category represent URS estimates of mercury emissions to air, indiscriminate disposal of mercury-containing drugs to land, and waste treatment plant disposal to water. The loss to air from mercury antiseptics and skin preparations probably does not exceed 10 percent of the total mercury content. Most of the mercury used in topical applications is ultimately lost to the water environment through cleansing of the mercury compounds attached to the body's surface. URS estimates that 95 percent of the mercury in mercurial diuretics is carried to water via human wastes. In all applications, a 5-percent loss to land reflects indiscriminate disposal of mercury-based drugs and containers by the American consumer. Overall, almost 90 percent of the mercury used by the pharmaceutical industry is lost to the water environment.

1983 Technology. No changes in the ultimate fate of mercury pharmaceuticals are expected by 1983. The use figures for the different applications will doubtless shift as the availability of alternatives, demands, and governmental restrictions change. The relative losses to air, land, and water, however, will probably be much the same as the 1973 figures.

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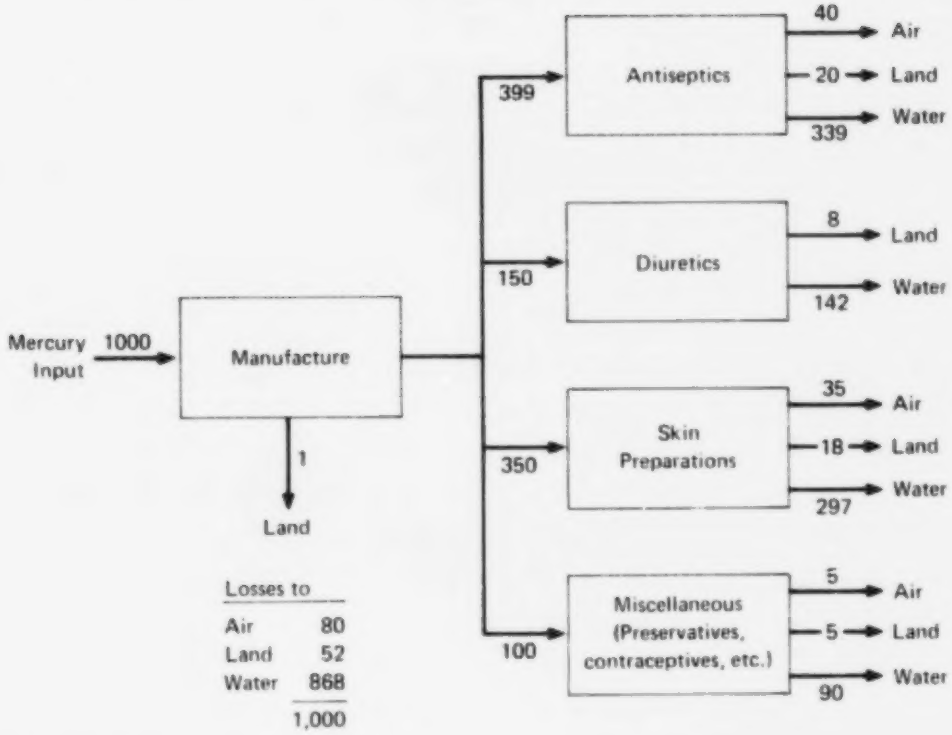
* The manufacture of pharmaceuticals is discussed under organic and inorganic mercurial manufacturing.


Mercury Input
1000
Manufacture
1
Land
399
Antiseptics
40
Air
20
Land
339
Water
150
Diuretics
8
Land
142
Water
350
Skin Preparations
35
Air
18
Land
297
Water
100
Miscellaneous (Preservatives, contraceptives, etc.)
5
Air
5
Land
90
Water

Losses to	
Air	80
Land	52
Water	868
	1,000

SOURCE: URS Research Company.

Figure 49 MERCURY BALANCE, PHARMACEUTICALS MANUFACTURE AND USE, 1973 TECHNOLOGY

Alternative Technologies. According to Ref. 68, one factor which hinders development of nonmercurial substitute pharmaceuticals is the need for certification of products by the Food and Drug Administration (FDA). Aside from the costs of development and testing, there is a significant time lag in processing new drug applications. Nonetheless, effective nonmercurial substitutes are available (Ref. 68). Considering that only limited amounts of mercury are used and eventually lost to the environment, though, it appears that the need for immediate controls is not critical.

The FDA has already ordered the removal of mercury from skin bleaching products and has limited the mercury content in cosmetics to less than 1 ppm in most cases. Because of the FDA fear that mercury compounds used for cosmetic preservation may be harmful to man as a result of permeation through the skin, controls on cosmetics would depend on the efficacy of weak static action substitutes. Similarly, the availability of antiseptic mercurials should be examined in terms of the antimicrobial alternatives that already exist. In cases where a particular mercurial pharmaceutical offers the physician a viable and unique alternative to a nonmercurial solution, restrictions might be counterproductive. As Goldwater (Ref. 70) explains, however, promotional advertising and the "mystery, magic, and mysticism of quicksilver" have contributed more to the perpetuation of the mercurials than have considerations of the irreplaceability and effectiveness of mercury medicine. Further research would probably reveal a number of areas where the use of mercury pharmaceuticals could be reduced or eliminated with no significant loss to "best practical" medical treatment.

Final Disposal Sector

Municipal Waste Treatment

The development of municipal waste treatment plant technology grew out of the need to protect community health. As citizen and governmental concerns broadened, these plants were improved to protect the environment and particularly the water that receives sewage discharges. This environmental awareness led to studies to determine the fate of heavy metals in such plants. Most of this work has been directed at lead, copper, cadmium, chromium, and nickel; very little work has been done on mercury.

In 1968, there were 12,565 municipal (community) treatment plants in the United States, treating the residential and industrial wastes of some 65 percent of the U.S. population (Ref. 96). Of these plants, 2,384 provided only primary treatment (removal of particulate matter only), 9,951 provided secondary treatment (primary treatment plus biological oxidation of most of the remaining organic matter, and 75 provided intermediate (between primary and secondary) treatment. These plants accounted for more than 99 percent of the total number of U.S. treatment plants, and served about 64.5 percent of the total population.

According to Ref. 97, in 1968 slightly more than 7 percent of industrial wastewaters were discharged into municipal treatment systems. Table 38 shows that community sewers in the Eastern Great Lakes region received the largest amounts of industrial wastes, and sewers in the Great Basin region (Nevada, Utah) received the least. The actual amounts may be a bit higher than the figures in Table 38 indicate, because those figure reflect only industries whose water intake was greater than 20 million gallons a year. As shown in Table 39, food and kindred products plants discharge the greatest amounts of wastewater to sewers, while lumber manufacturers discharge the least.

Although industry is generally responsible for large concentrations of heavy metals in sewage influents, the URS inventory results indicate that in the United States about 50 percent of the mercury in influents probably derives from the disposal practices of hospitals, dentists, and laboratories. A lesser proportion (possibly 25 percent) comes from the discharge of mercury-using manufacturing industries. Even less (15 to 20 percent) is attributable to human additions and other industrial contributions, and approximately 5 percent to 10 percent of the mercury in sewage influent is a result of natural background concentrations. Recent measurements (Ref. 98) have shown that the concentration of mercury averages about 1.5 ppb in sewers that receive residential discharges exclusively; in contrast, the national average mercury concentration in sewage influent as used in this report is 2.0 ppb.

TABLE 38. - Regional Distribution of Industrial Wastewater Discharges to Community Sewers in 1968

(billions of gallons)

Industrial Water Use Region	Total Industrial Wastewater Discharges	Percent Dis- to Community Sewers	Total Industrial Discharge to Community Sewers
New England	558.4	8.4%	46.9
Delaware and Hudson	1,191.9	7.3	87.0
Chesapeake Bay	754.7	4.3	32.5
Ohio	2,295.4	7.5	172.2
Eastern Great Lakes	1,459.7	13.9	202.9
Tennessee-Cumberland	535.9	2.6	13.9
Southeast	1,099.6	5.2	57.2
Western Great Lakes	1,811.3	7.4	134.0
Upper Mississippi	581.6	18.5	107.6
Lower Mississippi	744.6	3.1	23.1
Missouri	141.9	17.8	25.2
Arkansas-White-Red	184.6	7.9	145.8
Western Gulf	1,899.1	0.8	15.2
Colorado Basin	18.3	20.2	3.7
Great Basin	26.8	6.3	1.7
California	314.1	16.8	52.8
Pacific Northwest	532.5	5.7	30.4
National[a]	14,150.4		1,152.1

a. Excluding Hawaii and Alaska.

Source: Ref. 97

TABLE 39. - Wastewater Discharges to Community Sewers in 1968, by Industrial Category
(billions of gallons)

Industrial Category	Total Industrial Discharges	Percent Discharged to Community Sewers	Total Industrial Discharges to Community Sewers
Food and kindred products	752.8	31.6%	237.9
Textile mill products	136.0	37.2	50.6
Lumber	92.7	2.7	2.5
Paper	2,077.6	3.5	72.7
Chemicals	4,175.1	4.3	179.5
Petroleum and coal	1,217.0	0.6	73.0
Rubber	128.4	17.4	22.3
Leather	14.9	68.0	10.1
Stone, clay, and glass	218.4	9.4	20.5
Primary metals	4,695.5	3.1	145.6
Fabricated metals	65.0	59.4	38.6
Machinery	180.8	24.6	44.5
Electrical equipment	118.4	62.8	74.4
Transportation equipment	293.1	26.3	77.1

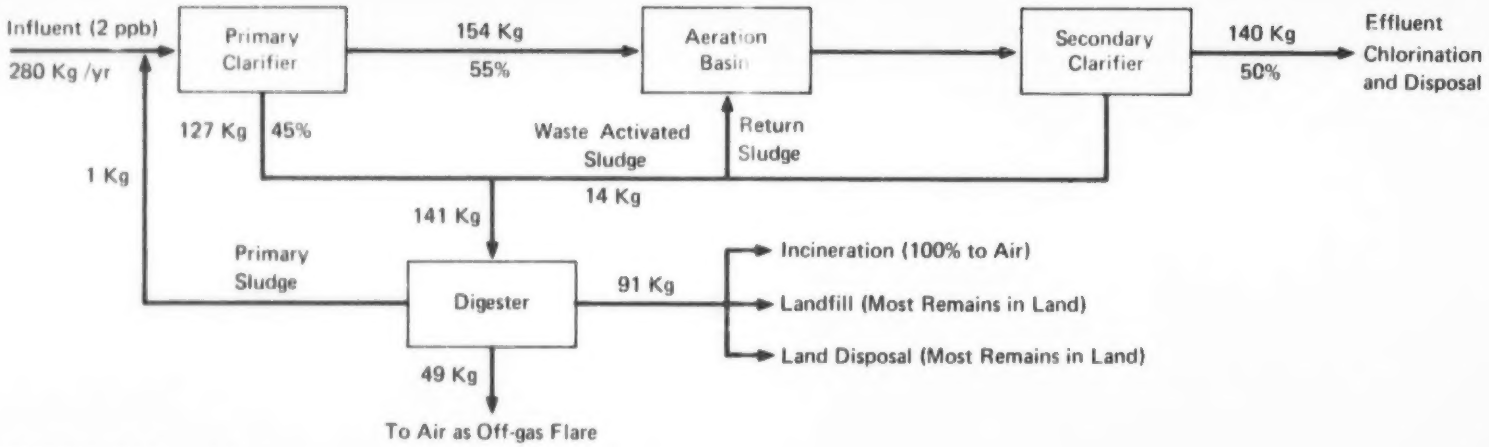
Source: Ref. 97

1973 Technology. There are various ways of treating municipal sewage, but as of 1973 most plants used secondary treatment processes--either activated sludge or trickling filters. As indicated above, about 65 percent of the community sewer systems surveyed by the Federal Water Quality Control Administration (FWQCA) in 1968 provided secondary treatment (Ref. 96). To comply with Public Law 92-500 (the Federal Water Pollution Control Act Amendments of 1972), all municipal waste treatment plants will have to provide secondary treatment by 1977.

Figure 50, a schematic of a typical activated sludge plant, shows the ultimate fate of influent mercury. Because mercury tends to adsorb on particulate matter, about 45 percent of the influent mercury is removed from the waste stream by the primary clarifier. The remaining mercury enters the aeration basin where aerobic bacteria metabolize the organic components of sewage. It has long been known that slugs of heavy metals can degrade or halt the proper function of these bacteria. However, experiments with mercury indicate that only abnormally high concentrations of influent mercury (probably over 10 ppm) would reduce bacterial efficiency (Refs. 99, 100). Similarly, high concentrations of mercury (between 1,000 and 2,000 ppm) in the biological sludge inhibit the sludge.

Because most of the biological sludge produced in the aeration basin is recaptured in the secondary clarifier and recycled, very little mercury (about 5 percent as a result of activated sludge wasting) is actually removed from the waste stream. The remaining mercury in the waste stream (about 50 percent) is then lost to the receiving waters (Refs. 101, 102). This mercury is both in solution and adsorbed onto the particulates that are not captured in the secondary clarifier (Ref. 103).

The digester, then, receives about 50 percent of the incoming mercury. Recent experiments have shown that almost all of the mercury remaining in the digester is in or on the solid phase (Ref. 104); consequently Figure 50 shows only a 1-percent recycle of mercury in digester supernatant (liquid formed on top of the digested solids as a result of settling and biological degradation) to the primary clarifier. Work by Bisogni and Lawrence (Ref. 100) indicates that at growth rates common to most digesters (residence times between 10 and


Influent (2 ppb)
280 Kg /yr
Primary Clarifier
154 Kg
55%
Aeration Basin
Secondary Clarifier
140 Kg
50%
Effluent Chlorination and Disposal
127 Kg
45%
1 Kg
Waste Activated Sludge
Return Sludge
14 Kg
141 Kg
Primary Sludge
Digester
91 Kg
Incineration (100% to Air)
Landfill (Most Remains in Land)
Land Disposal (Most Remains in Land)
49 Kg
To Air as Off-gas Flare

SOURCE: URS Research Company.

Figure 50 PATH OF MERCURY IN A 100 MGD SEWAGE TREATMENT PLANT

30 days) about 35 percent of the mercury coming into the digester on solids would be lost through volatilization; the remaining 65 percent would remain with the digested solids.

The remaining mercury in digested sludge may be disposed of in one of three ways--in landfill, as a soil amendment, or by incineration. The ultimate fate of this mercury depends on the disposal practice chosen. In brief, the mercury in digested sludge that is disposed of in sanitary landfills has reached its ultimate fate. Mercury in digested sludge applied as a plant fertilizer or soil amendment is bound somewhat less tightly as some may be lost through volatilization or erosion. Published studies indicate that all of the mercury in sludge that is incinerated reaches the atmosphere, and that assumption is used here.

1983 Technology. The municipal waste treatment technology that will be in effect by 1983 is also mandated by PL 92-500. According to this law, municipal plants must provide treatment that will protect the fish, shellfish, and wildlife of receiving waters and that will allow recreation in and on such waters. If present funding and construction trends continue, in 1983 the bulk of these plants will still be secondary treatment plants but a few plants will provide tertiary treatment (mainly phosphorus removal and multimedia filtration) in order to achieve higher quality of certain receiving waters (Ref. 105). Therefore, there will probably be no major changes in 1973 process technologies by 1983. However, the trend toward regionalization means that plants will tend to be larger, but there will be fewer of them than in 1973.

The major process difference will be in the final disposition of digested sludge. Greater use of sludge for fertilizer and soil amendment is expected, depending on the results of research on the fate of sludge-applied heavy metals and on the amount of vegetative uptake. Initial research indicates that the buildup and subsequent uptake of cadmium, copper, zinc and boron may limit the land application of sewage sludge, but that mercury causes no problem (Ref. 106). Greater control of industrial wastewaters influent to sewage treatment plants and recycling of mercury-containing compounds could reduce the concentrations of such heavy metals in sewage sludge. As industrial emissions account for about 35 percent of the mercury input, industrial reductions could have a significant effect. An even greater reduction would occur if institutional mercury users recycled more mercury. Although it is difficult to determine the extent of such reductions, URS assumes a 25-percent reduction in municipal sewer mercury disposal by 1983 as a result of the above reductions. URS also assumes that sludge incineration will decrease by 50 percent because of air pollution regulations (mercury and others) and energy conservation problems. Using these assumptions and the 1973 national inventory results, we have prepared Table 40, which lists estimated mercury losses to air, land, and water from sewage treatment facilities for 1973 and 1983.

Municipal Solid Waste Disposal

Municipal solid waste disposal systems are responsible for the collection, processing, and ultimate disposal (either in landfills or by incineration) of solid waste from residential, commercial, and light industrial areas. As with sewage treatment plants, these systems were developed to protect public health. Recently the design and operation of these facilities has also been directed at minimizing environmental harm, especially in the control of leachates from landfills and particulate emissions from municipal solid waste (Ref. 24). Because mercury has been found in landfill leachates (Ref. 107) and incinerator emissions (Ref. 108), these disposal practices must be examined in terms of their ability to introduce mercury in the environment. Collection and processing, on the other hand, contribute little (if any) mercury to the environment and therefore will not be discussed further.

Table 41 summarizes a recent national survey of solid waste management practices, listing the number and types of municipal landfill disposal sites by states and the number of municipal incinerators over 100 tons capacity (Ref. 109). These figures indicate that over half of the landfill sites do not meet regulatory requirements and might be apt to lose mercury to groundwater at a greater rate than do sanitary (regulated) landfills. The table also shows that incineration, which emits mercury directly to the atmosphere, is a common disposal practice on the East Coast.

The components of municipal solid wastes and their percent contribution by weight are paper products (60 percent), food wastes (8.5 percent), glass and

TABLE 40. - Estimated **Mercury** Emissions from U.S. Municipal Sewage Treatment Plants, 1973 and 1983 (kilograms)

Emissions to	1973[a]	1983[b]	Percent Change
Air	9,563	7,255[c]	-24%
Land	17,327	16,346	- 6
Water	19,923	17,482	-12
Total	46,813	41,083	-12%

Source: URS Research Company.

a. Derived from URS inventory.

b. Based on expansion of total U.S. population by 17 percent during 1973-1983 period and 25 percent reduction in mercury losses to municipal sewers by 1983.

c. Assumed 50 percent reduction in sewage sludge incineration.

TABLE 41. - National Solid Waste Disposal Practices

States	Total Landfill Sites	Landfill Sites Meeting Regulations	Municipal Incinerators
Alabama	143	134	0
Arizona	160	70	0
Arkansas	450±	47	6
California	441	302	1
Colorado	255+	380	0
Connecticut	144	209	23
Delaware	150	39	0
Florida	500	204	10
Georgia	625	275	0
Idaho	190	50	0
Illinois	404	225	4
Indiana	151	220	1
Iowa	500	36	0
Kansas	300	160	0
Kentucky	147	147	2
Louisiana	387	61	4
Maine	367	0	0
Maryland	91	106	4
Massachusetts	324	171	18
Michigan	888	379	10
Minnesota	600	131	-
Mississippi	274	54	0
Missouri	390	136	3
Montana	514	70	0
Nebraska	400	123	0
Nevada	120	120	-
New Hampshire	180	180	4
New Jersey	307	276	3
New Mexico	1,000	450	0
New York	800+	800+	39
North Carolina	162	156	0
North Dakota	412	-	0
Ohio	290	270	13
Oklahoma	507	354	2
Oregon	241	313	0
Pennsylvania	379	129	20
Rhode Island	38	7	2
South Carolina	276	276	0
South Dakota	369	32+	0
Tennessee	250	112	1
Texas	1,525	346	4
Utah	272	7	1
Vermont	95	75	1
Virginia	188	346	4
Washington	397	73	0
West Virginia	300+	66	0
Wisconsin	1,314	1,200	6
Wyoming	80±	-	0
Total	18,539+	9,212	189

Source: Ref. 109

ceramics (8.0 percent), metals (8.0 percent), plants and grass (6.5 percent), plastics (3.5 percent), and others (5.5 percent). Although most of these materials may contain traces of mercury, the major contributors--all found in the "other" category--are batteries, control instruments, fluorescent and other mercury-containing lamps, and tubes and switches. They account for only a small percentage of the "other" solid waste category yet are believed to account for virtually all of the estimated 2 to 6 ppm mercury content of solid wastes. (Paper products, before mercurials were banned in this usage, also represented an appreciable source of mercury in solid wastes, but by the year 1973 the amount of such treated paper products in solid wastes was assumed to be low.) Furthermore, these "concentrated" solid wastes represent, on the average (based on all study regions inventoried by URS), 96 percent of all mercury wastes which are rejected to land.

1973 Technology. The 1973 technology for solid waste disposal is based upon the usage of well accepted sanitary landfill and municipal incinerator technology in simple combinations. Important aspects of sanitary landfill practice with regard to potential mercury contamination include site selection, design, and operation. Landfill sites should be selected to ensure minimum contact with groundwater. Designs should provide for adequate drainage and, if groundwater is a problem, should provide for the placement of impermeable clay barriers and gravel drains to prevent groundwater intrusion. Impermeable linings are also being used more extensively to seal landfills, but as of 1974 only 21 (out of more than 18,000) were in place.

Operations and maintenance activities should be such as to guarantee the placement of adequate daily and final cover which ensures sanitary operations. While there is no evidence that ground cover will stop the leakage of mercury to air, the topsoil layer has been shown to be effective in controlling the release of decomposition gases (primarily methane and carbon dioxide) which undoubtedly contain trace amounts of mercury.

Recent work done on sanitary landfills indicates that the mercury concentration of leachate within the landfill varies between 0.05 and 16.3 ppb, with a considerable number of data points above the proposed EPA Drinking Water Standard of 2.0 ppb (Ref. 107). However, other work indicates that the attenuating action of soil effectively lowers the mercury content of leachate as it passes through the lower soil boundary. These results lend credence to the acceptability of the modern sanitary design, operation, and maintenance principles now being followed by the individual states and to the ability of sanitary landfills to provide safe, long-term storage sites for mercury contained in municipal solid waste.

The municipal incinerator, on the other hand, is a direct emitter of mercury to the atmospheric environment. Recent work indicates that about 90 percent of the incoming mercury is volatilized and lost to the atmosphere (Ref. 109). The remaining 10 percent remains in the ash for ultimate disposal in a sanitary landfill. The flow of mercury in municipal solid waste from a typical city of 500,000, using typical 1973 technology, is shown in Figure 51, which indicates that most of the mercury remains bound within the landfill.

1983 Technology. As shown in Figure 52, solid waste disposal technology and practice by 1983 will probably be considerably different from what was commonly being practiced in 1973.* The greatest difference will be in the fields of material and energy recovery, hazardous material disposal and fate, and the regulations under which solid waste disposal now operates. Increased resource recovery--particularly materials recovery--would have the greatest effect on mercury emissions by reducing the amount of concentrated mercury-containing wastes going to incinerators and possibly to landfills. As was mentioned previously, the mercury content of solid waste appears to be concentrated in discarded batteries, fluorescent lamps, tubes and switches, and control instruments. Therefore separation of the light and heavy solid waste fractions influent to a municipal incinerator would result in a significant reduction in atmospheric mercury emissions. At the present time there are about 38 major resource recovery facilities, not all of which are connected to incinerators (Ref. 109). The main process for such separation would be the air classification method.

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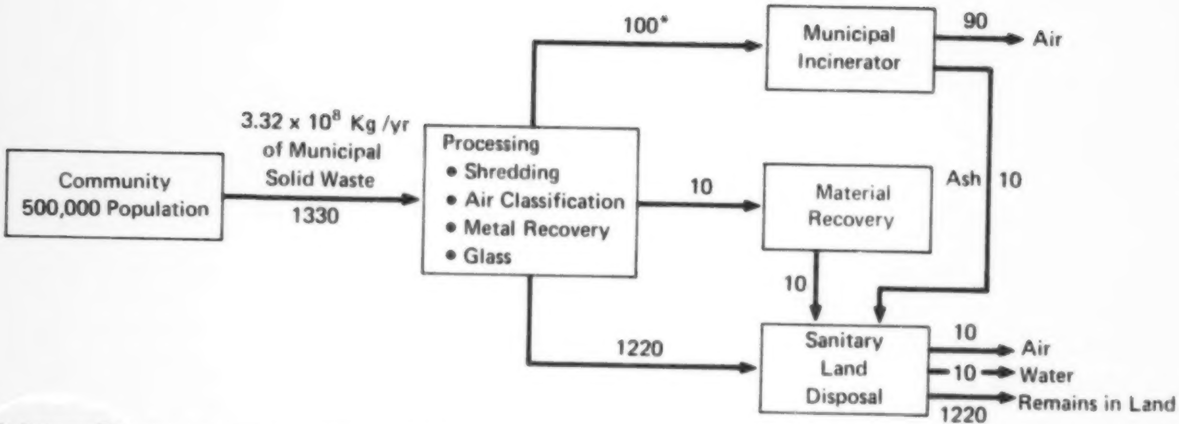
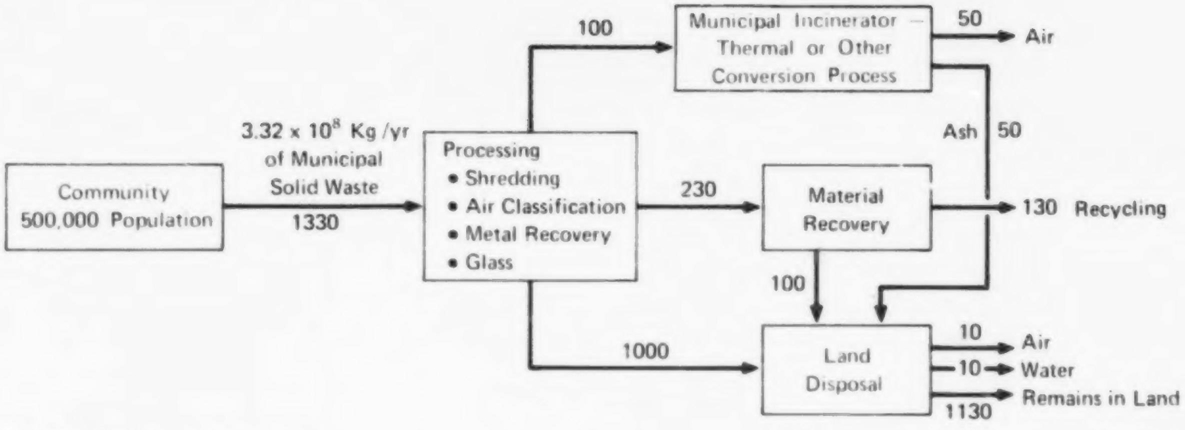
* The same input of mercury into solid wastes is assumed for 1983 as for 1973 because, although total quantities of solid waste are projected to grow, the amount of mercury-containing wastes discarded is likely to level off or decline.


100*
Municipal Incinerator
90
Air
3.32 x 10^8 Kg /yr of Municipal Solid Waste
Community 500,000 Population
1330
Processing
• Shredding
• Air Classification
• Metal Recovery
• Glass
10
Material Recovery
Ash
10
10
Sanitary Land Disposal
1220
10
Air
10
Water
1220
Remains in Land

* Assumes 8 percent of all solid waste is incinerated.

SOURCE: URS Research Company.

Figure 51 FLOW OF MERCURY IN THE MUNICIPAL SOLID WASTE STREAM OF A TYPICAL COMMUNITY OF 500,000 IN 1973 (kilograms per year)


Municipal Incinerator – Thermal or Other Conversion Process
100
50
Air
Ash
50
3.32 x 10^8 Kg/yr of Municipal Solid Waste
1330
Community 500,000 Population
Processing
• Shredding
• Air Classification
• Metal Recovery
• Glass
230
Material Recovery
130 Recycling
100
1000
Land Disposal
10
Air
10
Water
Remains in Land
1130

SOURCE: URS Research Company.

Figure 52 FLOW OF MERCURY IN THE MUNICIPAL SOLID WASTE STREAM OF A TYPICAL COMMUNITY OF 500,000 IN 1983 (kilograms per year)

Whether increased material recovery would result in significantly less mercury loading to landfills would depend upon the possibilities for extracting mercury from the nonferrous metal waste stream. As mercury is highly volatile, it is possible to extract mercury metal from that fraction by roasting and subsequent condensation. However, the economics of this process versus virgin sources and other recycled material are not promising, and its adoption appears unlikely.

Much research is now being funded to determine the fate of hazardous materials in landfills and to develop procedures for reducing their adverse impacts, if any. Measurements of mercury from landfill leachates outside of the landfill have not shown anomalously high mercury concentrations, which indicates that sanitary landfills, when properly designed and operated, effectively remove the mercury contained in municipal solid waste from the environmental cycle.

Changes in government regulations could affect the kinds of material in solid waste and the disposal practices. The success of sanitary landfills in retaining mercury from municipal solid waste probably indicates that regulations removing mercury from solid waste destined for such landfills are not needed; however, upgrading unregulated landfills should be speeded up. On the other hand, forces fostering the construction and operation of resource recovery and thermal conversion facilities would cause more mercury to reach the atmosphere. If regulations were promulgated which mandate the removal of most of the mercury from the process stream, mercury emissions to air could be reduced significantly.

Because sanitary landfills are more economical to run than incinerators, and because strong demand for recycled waste streams is still unproven, sanitary landfills will probably remain the dominate final disposal method. In 1973 land disposal accounted for about 93 percent of all solid wastes, while in 1983 land disposal will probably receive only about 75 percent of total municipal solid wastes. This reduction in the percent of disposal to land is a result of increases in material and energy recovery and reclamation. URS combined these trends in solid waste disposal with improvements in pollution control (better capture of mercury emissions from thermal conversion units, landfill upgrading) to derive Table 42, which shows estimated environmental losses of mercury from solid waste disposal activities for 1973 and 1983.

TABLE 42. - Estimated Mercury Losses to Environment from U.S. Municipal Solid Waste Disposal, 1973 and 1983 (kilograms)

Losses to	1973	1983[a]
Air	40,000	24,000[b]
Water	18,000[c]	6,000
Land	466,000	448,000
Reclamation	-	52,000
Totals	530,000	530,000

Source: URS Research Company

a. Assuming total amount of mercury in solid waste stream will remain constant, even though the total quantity of solid waste will increase.

b. Assuming a 100 percent increase in thermal conversion processes (incineration, pyrolysis, etc.), all operating with front-end material recovery units and air pollution control units capable of 50 percent mercury recovery.

c. Assuming improperly operated landfills and dumps lose mercury to water at twice the rate of regulated fills.

MACROTECHNOLOGY (1973)

For industries that manufacture primarily consumer goods, the losses of mercury to the environment may extend from the manufacturing process itself, to other (secondary) manufacturing and processing, to final consumption and disposal. To obtain the necessary perspective on these losses from the various sectors involved, composite flow charts showing overall losses have been prepared for the applications of mercury that involve sequential losses. Table 43 summarizes total mercury losses for five such applications. Flow charts indicating the details of these losses to the environment are given in Figures 53 and 54 for the two largest consumers of mercury--electrical applications and paint. (Details on the source of discharges for other applications can be obtained by referring to the appropriate subsections in the preceding discussion of microtechnologies.)

With the exception of catalyst usage, most losses occur in the final consumption sector. Recycling is an important consideration only for industrial instruments; here recycling accounts for almost half of the mercury used by the industry. In general it can be concluded that while manufacturing and processing represent the most logical and the easiest points at which to apply controls over mercury losses, they also are the least rewarding in terms of significant reductions in mercury emissions.

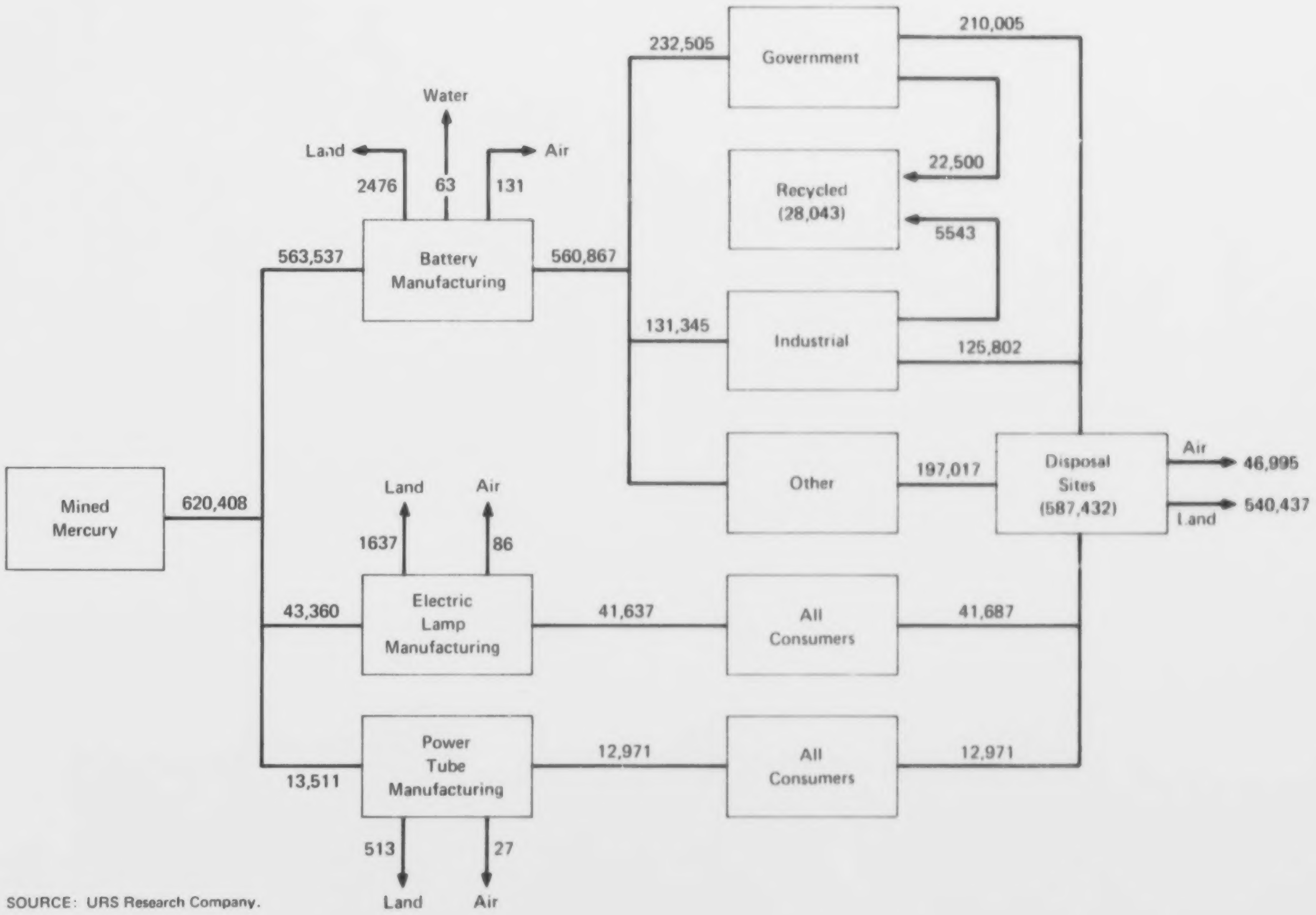
IMPLICATIONS

With respect to the various technologies and composite technologies described in this section, it is generally forecast that there will be appreciable reduction in mercury emissions between 1973 and 1983. Most of these reductions will come about from improved utilization of mercury (through recycling either within the plant or of products containing mercury) or by the imposition of effective pollution controls. In some of the lesser technologies, for example, livestock manure, specific reductions were not discussed, the implication being that the loss to the environment, while large in aggregate, is diffused geographically and hence pose no threat to human safety.

TABLE 43. - Mercury Losses for Various Applications, 1973

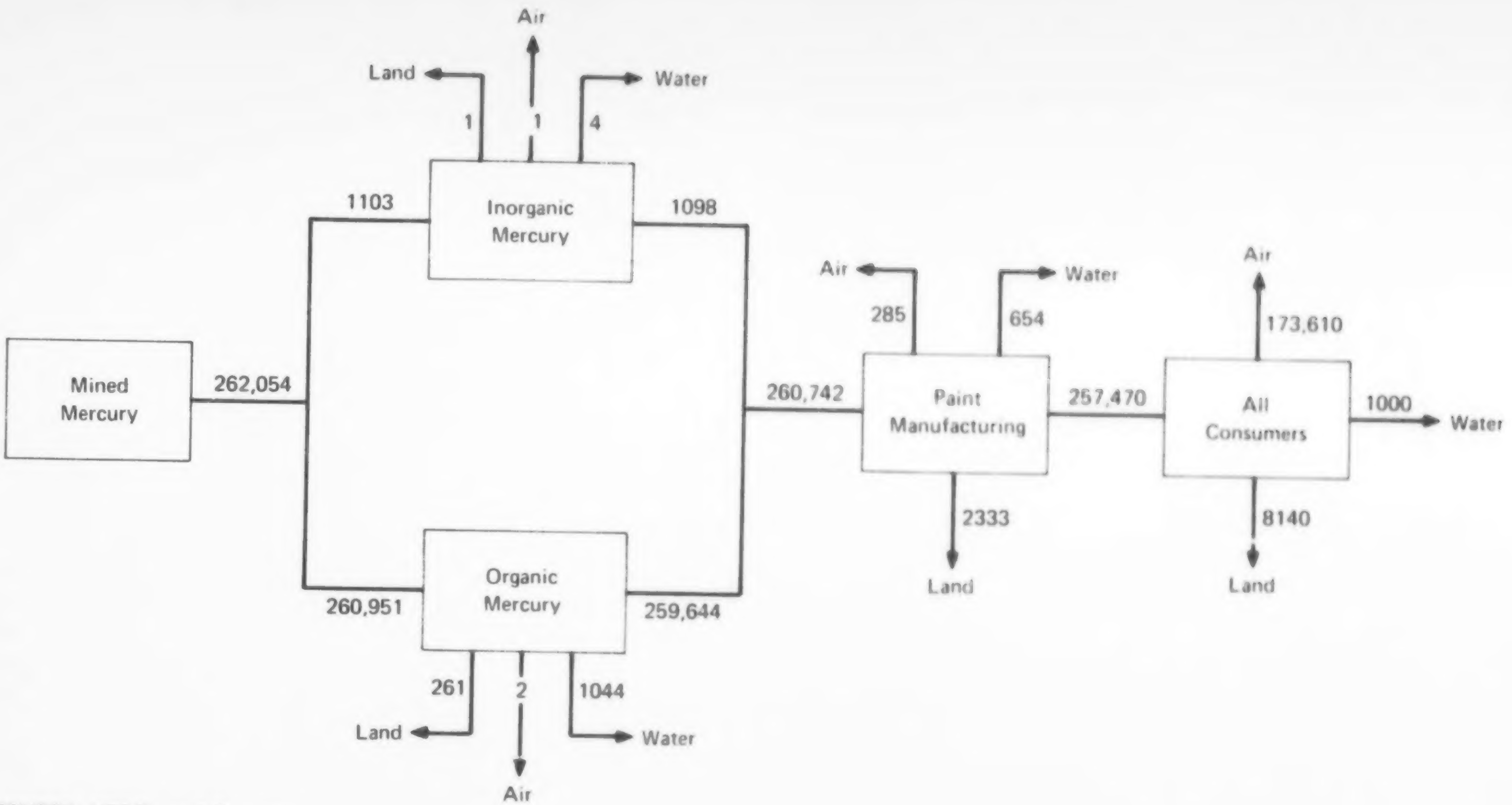
Application	Total Usage (kilograms)	Total Losses in Kilograms to Environment during			Ratio of Total Loss to Total Use
		Manufacture	Processing	Final Consumption	
Electrical	620,408	4,932	-	587,433	0.955
Paint	260,330	1,312	3,272	182,750	0.720
Industrial Instruments	246,612	3,169	-	124,040	0.516
Pharmaceuticals	20,887	126	126	20,000	0.970
Catalysts	23,403	17,473	1,766	1,945	0.905

Source: URS Research Company


Mined Mercury
620,408
563,537
Battery Manufacturing
Land
2476
Water
63
Air
131
560,867
232,505
Government
210,005
22,500
Recycled (28,043)
5543
131,345
Industrial
125,802
Other
197,017
Disposal Sites (587,432)
Air
46,995
Land
540,437
43,360
Electric Lamp Manufacturing
Land
1637
Air
86
41,637
All Consumers
41,687
13,511
Power Tube Manufacturing
513
Land
27
Air
12,971
All Consumers
12,971

SOURCE: URS Research Company.

Figure 53 SEQUENTIAL MERCURY LOSSES IN ELECTRICAL APPLICATIONS, 1973 (kilograms)


Air
Land
Water
1
1
4
1103
Inorganic Mercury
1098
Mined Mercury
262,054
260,742
Air
285
654
Water
Paint Manufacturing
257,470
Air
173,610
All Consumers
1000
Water
2333
Land
8140
Land
Organic Mercury
260,951
259,644
261
2
1044
Land
Water
Air

SOURCE: URS Research Company.

Figure 54 SEQUENTIAL MERCURY LOSSES IN PAINT APPLICATIONS, 1973 (kilograms)

In general, it appears that users and emitters of mercury have been thoroughly alerted to the inherent dangers of such emissions and have taken the necessary actions to limit or eliminate them entirely. While this trend is indeed praiseworthy, it must be recognized that it may not be sustained without effective enforcement. Hence, even in industries which can demonstrate or forecast adequate self-policing, regulations may be necessary to ensure continued compliance.

Even with improved technology, increased recycling, and concern on the part of the industries involved, high losses to the environment will still persist in some categories:

- The chlor-alkali industry, assuming the continued operation of existing plants with vastly improved pollution control technology and utilization of mercury, will in 1983 continue to emit appreciable quantities of mercury to the environment in localized areas.
- The paint industry, assuming continued use of mercurials and even with the best of controls, will continue to be a major contributor of man-related emissions to air in 1983.
- Electrical usage (including batteries, lamps, and tubes and switches), even with vastly improved recycling, will continue to contribute vast quantities of mercury to landfills and, unless stringent regulations are imposed, to incinerators and thence to the air. To a lesser extent, the same comments apply to control instruments.

Since these three categories have been identified as important and continuing emitters of mercury to the environment, albeit to safe disposal sites, these industries are considered in Section V in a detailed analysis with respect to the impact of regulatory actions which would serve to further reduce their emissions to the environment.

It is difficult to assess the hazard posed to man and his environment by man-related emission sources as contrasted to the hazard posed by natural sources. As has been shown, continuing action has reduced man-related emissions significantly and will continue to do so for some years in the future. However, natural emissions of mercury, from degassing and runoff, will remain unchanged (or could even increase appreciably if, for example, unusual volcanic activity occurred). It is legitimate to ask: Why spend millions of dollars to reduce mercury emissions from, say, a power plant when such emissions to air are very small compared to those from degassing from the earth's crust? First, we must admit that man can control only his own release of mercury to the environment, and that if he believes that mercury releases should be minimized, he must concentrate on that which is controllable. Second, and perhaps more important, natural sources of mercury into the environment are diffuse and relatively uniformly distributed (across the nation and the world), and have not been demonstrated (or even inferred) to concentrate to the extent of interfering with man's food chain. On the other hand, man's wastes do follow his habitat. They do concentrate where he lives, and have on certain unusual occasions concentrated sufficiently to enter the food chain and threaten man's well-being. Hence, man-related discharges of mercury, even though small, interact with man and his environment more directly than do natural sources.

V

REGULATORY IMPACT ANALYSIS

INTRODUCTION

In this section we discuss the ways in which regulatory actions might be used to reduce the quantities of mercury discharged to the environment by man-related activities. Three major emissions contributors--chlor-alkali plants, final consumption of paint, and final consumption of batteries--are examined. These three examples also provide insight as to how controls might be applied in related industries or usages.

Chlor-alkali plants represent a manufacturing industry that uses large quantities of mercury each year and loses appreciable amounts of this mercury to the environment (although in a form that has not been shown to be unsafe). In this small but important industry mercury losses are limited to the manufacturing process only; thus this example can be used to illustrate how controls might be applied to clearly defined point source emitters.

Final consumption (and disposal) of batteries creates mercury losses primarily to landfills and incineration. This example typifies the solid waste losses of several other electrical applications, including tubes/switches, lamps, and industrial control instruments. In the case of batteries, manufacturing losses are small but overall losses, including those created by ultimate disposal of the used product, are large. These latter types of discharges are considered to be area sources (as contrasted with point sources), and regulation at their points of release (or disposal) may be impractical. Therefore we explore the usefulness of regulation at the "point" source--that is, at the manufacturing level--as a way of reducing losses at the consumer's end. This type of regulation relies heavily on recycling. However, the impact of such regulation of point sources affects the entire economic chain from mercury production through final sales, and is therefore considered as a part of the derived costs in our cost-benefit analysis.

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Relatively little mercury is lost in the manufacturing and processing of paint. Most of the mercury emissions from paint occur after its final application, and most of these losses are to air. No control is possible at this point (and again there is little or no evidence to indicate a hazard to health). Therefore only one regulatory action--the elimination of mercurials from paint--can be envisioned. The impacts of such a regulation would be felt by suppliers of mercury, manufacturers of mercurials, paint formulators, wholesale and retail distributors, and ultimately the consumer.

Three cost-benefit analysis (CBA) alternatives have been proposed (although not all are applicable to any given case):

- o Substitution of a nonmercury-containing material or end product for one that contains mercury or uses mercury in its production.
- o Use of alternative processes that can produce the desired material or end product without the use of mercury.
- o Imposition of mercury emission controls that will substantially decrease the losses of mercury to the environment, either in production processes or in end uses.

Because there is virtually no knowledge concerning the health hazards which may be associated with exposure to low levels of mercury (that is, levels far below the published standards shown in Figure 5), it is not possible to demonstrate a benefit for reduction of mercury emissions when they are initially below established "safe" limits. In lieu of a demonstrated benefit we have elected to use a stated benefit--the estimated reduction in the quantity of mercury emitted that is attributable to the implementation of a given alternative. This accrued benefit may be expressed as a fraction, thus:

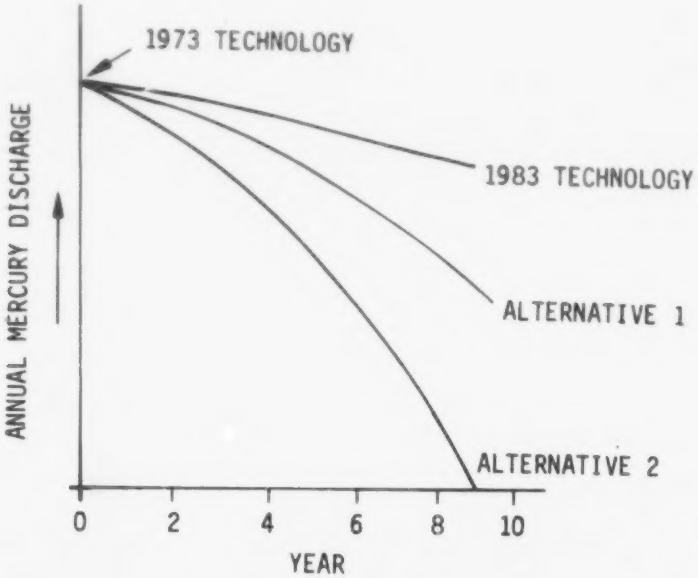
$$\frac{\text{Total mercury release with the alternative}}{\text{Total mercury release without the alternative}}$$

Each alternative has costs attached to it. These costs, both direct and indirect, are determined as the second step of the CBA.

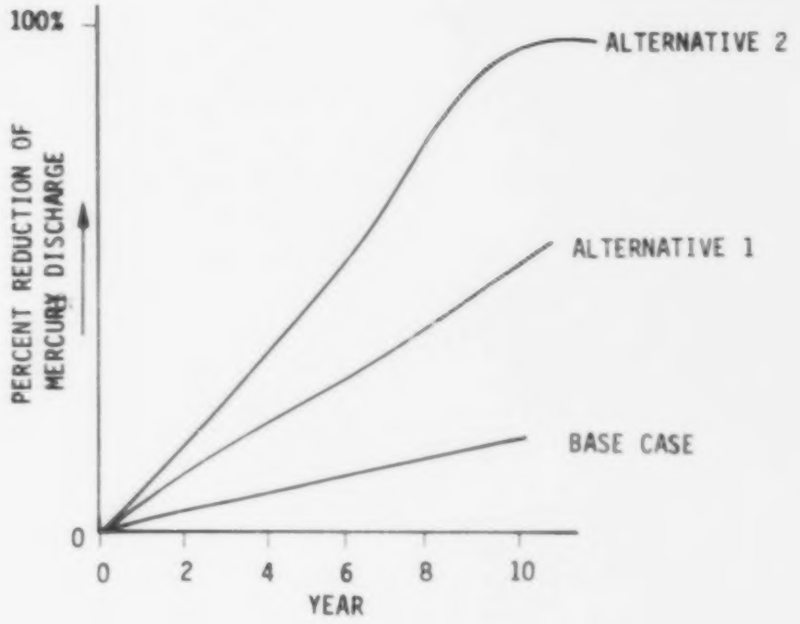
Finally, each alternative is considered in the light of the possible risks it may entail. One type of risk is that the alternative may in itself lead to the introduction of other toxic or hazardous materials into the environment; the second type of risk is that disbenefits, in terms of acceptability or effectiveness of the substitute, may result. Since benefits are not treated

METHODOLOGY

Benefits are extremely difficult to identify, much less to quantify. In the case of mercury this is doubly true, since its toxicity can only be demonstrated at relatively high emission levels--far beyond those considered safe for continued exposure--yet the quantifiable benefit of reducing intake below "unsafe" levels cannot be demonstrated. Also, mercury enters the environment from natural sources that contribute to the total mercury burden. Although definitive data on benefits are lacking, it can be presumed that unnecessary introduction of mercury into the environment, and thence into the food chain, is undesirable. We have therefore chosen as our criterion for benefit the reduction in the amount of man-related mercury which enters the environment that can be effected by employing a given alternative. This reduction is estimated in terms of projected mercury consumption by the contributor under study over the 10-year period 1973 to 1983. (Since mercury consumption in general is going down for certain consumers, it is necessary to include this declining curve.) The reduction is then compared with the estimated consumption for each alternative. An example of how such a curve might look is sketched below.



For a given year, the reduction in the amount of mercury used under the control situation versus that for the alternative is plotted. A second curve can then be derived (see sketch below) which indicates the percent reduction in mercury use versus time. For each curve a cost can be attached for the total period (in this case, 10 years). The CBA results then become a problem of choice for the planner in terms of the willingness and ability to allocate sufficient money to reach the desired objectives.



Costs are not as difficult to estimate as are benefits in this case, but cost estimating is still difficult. Costs may include costs to the manufacturer who may have to change his technology or his product, costs to society in terms of displaced workers and equipment, cost to the consumer in terms of a less effective product, etc. In short, a ripple effect can be traced. However, other alternatives (which are less complicated but which will suffice for the present analysis) are used as appropriate for each of the three major industries studied.

Cost estimates for the chlor-alkali industry were limited to those that could be identified as manufacturers' capital investments for adoption of new technology which could be mandated specifically for the industry. Costs for the battery and paint industries were extended to include all associated costs, since regulations, even though imposed at the manufacturer's level, have implications at all levels from mercury mining through final consumption of the end products.

The risks associated with each alternative could reduce the overall benefit associated with that alternative. But we are not directly identifying benefit, so risks identified for an alternative are treated as part of that alternative's costs. For example, the removal of lead discharges from diaphragm cells that replace mercury cells for the production of chlorine would be treated as a cost -- primarily an operating cost.

REGULATION IN THE CHLOR-ALKALI INDUSTRY

Chlor-alkali producers who use mercury cell technology are already subject to regulation with respect to allowable emissions of mercury to the environment and, although some producers are still not in compliance, the necessary actions to comply are under way. But the industry still emits large quantities of mercury, primarily to land, and in this section we consider regulatory actions that might be taken to further decrease such emissions. The alternatives that might involve regulatory actions include:

1. Eliminating the demand for chlorine and caustic soda by substituting other chemicals and/or other end-use technologies.
2. Altering the technology of producing chlorine and caustic soda to end the use of mercury altogether.
3. Tightening enforceable controls or regulations to minimize the emissions of mercury to the biosphere.

Alternative 1--Elimination or Substitution of Product

Chlorine is one of the basic "building blocks" of chemistry and is one of the largest volume industrial chemicals. More than 10 million tons of chlorine were used in the United States in 1973; about one-fourth of this was produced using mercury cell technology. Almost 50 percent of all chlorine produced is used in the synthesis of miscellaneous organic chemicals, and an additional 19 percent in the synthesis of vinyl chloride--another organic. Elimination of chlorine or substitution of another material for these uses is not feasible. Substitutes for chlorine have been developed for some smaller volume uses. Sanitation and water treatment use an estimated 5 percent of all chlorine production. The use of ozone and iodine (or compounds) has been adopted by some users in place of chlorine for water treatment, but to date the acceptance level is low, and there has been only a minor impact on the demand for chlorine.

Caustic soda and caustic potash, which are produced simultaneously with chlorine in approximately equivalent quantities, are also basic chemicals that are used in a variety of industrial applications. Some substitution is possible here; for example, the choice can often be made between caustic soda (NaOH) and soda ash (Na_2CO_3). However, the choice of caustic soda is often determined by economics: its supply is dictated by chlorine production patterns and the resultant caustic soda must be sold, often at prices which beat out other competitive chemicals.

It is our conclusion that elimination of these products--chlorine and caustic--or substitution of other materials is not feasible and can be discarded as a possible alternative.

Alternative 2--Alternate Technologies

The use of alternate technologies is already feasible, because more than three-quarters of the chlorine and caustic soda produced comes from diaphragm electrolytic cells which use no mercury. Mercury cells and diaphragm cells have often been compared, and the mercury cell is the most favored choice. However, the advantage of the mercury cell (which is basically the production of a concentrated, salt-free caustic) has been largely negated by the major disadvantage of mercury emission problems. Mercury cell technology does not have a clear economic advantage over diaphragm cell technology and does have a disadvantage with respect to requirements for control of mercury emissions--some unregulated discharges prior to an understanding of the problems entailed resulted in some bad publicity for the industry. Therefore the industry has, on its own, shifted to the diaphragm cell for new plant technology. In 1968 about 30 percent of the chlorine produced came from mercury cells. In 1970 this had dropped to around 28 percent; in 1972, to 24 percent; and in 1973, to less than 24 percent. It is noteworthy that all new caustic chlorine units are diaphragm cells (Ref. 140). And even with the technology of the diaphragm cell, there are substitute materials that improve power utilization while eliminating the asbestos (itself a pollutant source) in the diaphragm. DuPont's Nafion, a nonasbestos material, is now in commercial use, and in Japan both Asahi Glass Company and Tokuyama Soda Company have their own nonasbestos synthetic membranes under development.

In this case straight substitution of the diaphragm technology for the mercury cell process is deemed technically feasible. Since no unreasonable differences in the final products result, there are no impassable barriers to the changeover other than the costs of making the change. The major disadvantage of the conventional asbestos diaphragm cell is that it produces a more dilute caustic which contains salt. To produce a generally useful product, concentration of the caustic from 11 percent to 50 percent and lowering the salt content from 15 percent to 2 percent must be achieved. This process requires large amounts of thermal energy, offsetting much of the cost advantage of the higher electrical efficiency of the diaphragm cell.

To change the mercury cell chlor-alkali plants to diaphragm or synthetic membrane plants would involve significant costs. These costs would include new capital investment for land and facilities, the assumption being that existing mercury cell plants would be kept operating to meet market demands for product until the replacement units were on-stream.

Data for 1971 from Ref. 63 give the capital investment required for a 100-ton/day plant as $8 million. (This includes a $540,000 credit for mercury recovered.) Also for 1971, the annual operating costs for such a plant are given as being in the range of $2.4 million, equivalent to about $73 per daily ton of chlorine. Later data (1974) from unpublished sources give an operating cost (raw materials, energy, labor and maintenance) for such a diaphragm cell plant of $84 per daily ton of chlorine.* These sources also provided cost data on mercury cell plants which indicated that operating costs per ton of product are virtually identical for either route when the costs include those for the purification and concentration of caustic from diaphragm cell plants.

Using these 1974 data, it was assumed that the only major cost for converting from mercury cells to diaphragm cells would be the capital investment. At $8 million per 100-ton/day capacity, it would require new investment on the order of $610 million to produce the 2.5 million tons now produced by mercury cell technology; assuming a 15-year depreciation period, the depreciation cost would average $16 per ton of chlorine** (compared to the current estimated production cost of $84 per ton). The changeover to diaphragm technology would represent a hardship on mercury cell producers only if imposed over a brief and arbitrary period, forcing simultaneous monetary requirements for old plant operation and new technology investment.

The benefits of the conversion would be the removal of as much as 326,000 kg of mercury discharges to the environment each year. Since the total man-originated contribution for all sources studied in this analysis amounts to 1,525,000 kg annually, this would represent a decrease of about 21 percent. At the same time, the dismantling of all mercury-using chlor-alkali plants would release an estimated 3.6 million kg of the metal to the market. (As previously noted, the value of this mercury has been credited in accounting for the capital investment required to convert to diaphragm cells.)

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* Confidential information obtained during field contacts by URS Research Company.

** Depreciation costs are, of course, included in total cost. In the case of chlorine from mercury cell plants it must be recognized that most of these plants are at least six years old and on the average are probably at least half depreciated. Also, a portion of the $16 per ton might be charged to the co-product, caustic soda, but since chlorine demand is normally the determining factor, such an allocation would be difficult and ultimately arbitrary.

Alternative 3--Increased Control

The present technology of control of mercury emissions is recognized as being capable of reducing mercury emissions to the biosphere from the 1973 average 0.37 lb/ton (0.185 kg/metric ton) of chlorine to about 0.25 lb (0.125 kg) and, with more stringent controls, to a level of 0.04 lb/ton (0.020 kg/metric ton) (Ref. 141). However, a more realistic goal for 1983 is 0.10 lb/ton of chlorine (0.05 kg/metric ton). To relate such a reduction to the individual losses to air, water, and land, we have examined certain control technologies which will reduce emissions:

Air. Molecular sieves for use on hydrogen and end box ventilation streams have the capability of reducing the mercury content of these streams by 95 percent over current EPA standards (from 1.0 kg/day to 0.045 kg/day). Cell room ventilation losses, which currently are set at a maximum of 1.3 kg/day, are unlikely to be affected by new technology (although the amount of daily emissions may be lowered through better housekeeping).* Hence daily overall losses to air, assuming an operating removal efficiency for the molecular sieve unit of 90 percent, cannot be reduced by more than 40 percent.

Water. Sulfide precipitation treatment for final polishing of water effluent from the plant has the capability of reducing discharges to water by more than 94 percent.

Land. High temperature roasting of sludges in multiple hearth furances can recover more than 99 percent of the mercury content. Other solid waste losses, such as graphite from decomposers and miscellaneous contaminated wastes, are not considered amenable to such recovery practices, however; since these represent about 23 percent of solid waste losses, the maximum reduction possible is 78 percent, assuming a conservative recovery of mercury from sludge of 97 percent.

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* Concentrations of mercury vapor in cell rooms might be appreciably reduced if the industry as a whole were to adopt the "open air" cell room concept now in use at FMC's Squamish, British Columbia, plant (Ref. 142). However, this concept would not reduce total emissions to air.

The cost of pollution control equipment was derived from several sources and the total cost (in constant dollars) for the industry was estimated using the familiar "0.6" rule (Ref. 63). Operating costs were similarly estimated where possible. The basis for these cost estimates is discussed briefly below.

Reference 63, which provides a comprehensive analysis of the cost of control and conversion for the chlor-alkali industry, indicates a capital cost in 1973 of $349,000 for a molecular sieve unit for a 100 ton/day facility, with annual operating costs of $105,000. The total cost of equipping all 28 mercury cell chlor-alkali plants with such devices is calculated to be $8.6 million, with total annual operating costs of $2.6 million. A review of the trade journals and contacts with representatives of the industry indicates that these are reasonable estimates. The use of other control technologies, such as treated activated carbon, would have similar values attached for cost and efficiency.

The use of sodium sulfide to precipitate the very insoluble mercuric sulfide seems to be generally accepted as the least expensive, most trouble-free, and most effective method for removing traces of mercury from effluent waters prior to discharge. References 68, 141, and 143 describe several variations of this treatment, including results for both pilot and operating plants. Cost data were conflicting--Ref. 141 indicates a capital investment of $500,000 for a sulfide treatment unit for a 175 ton/day (chlorine) capacity plant, whereas Ref. 143 indicates a capital cost of only $143,900 for what appears to be a plant of the same size. Hence in our estimate we assume an average capital cost of $300,000, with an annual operating cost of about $100,000. Thus the estimated total capital cost for equipping all 28 plants in the nation with this type of technology would be $10.1 million, with total annual operating costs of $1.5 million.

The use of sodium borohydride treatment is considered an acceptable alternate to the use of sodium sulfide (Ref. 143), but the costs are somewhat higher and the efficiency is slightly less. Activated carbon has also been tested but appears to be less suitable than sodium sulfide.

Two competitive technologies have been identified for the recovery of mercury from sludges: high-temperature roasting of sludges (the so-called Georgia-Pacific process, described in detail in Ref. 143) and solubilization of mercury and its compounds by a hypochlorite solution and subsequent reduction of the dissolved mercury to elemental mercury in the chlorine cell (as described in U.S. Patent 3,691,037, 12 September 1972, assigned to FMC Corporation, Squamish, B.C.). Capital costs for the roasting technology (from Ref. 143) are estimated at $364,500 for a 200-ton/day (chlorine) facility with annual operating costs of about $100,000. Costs for the alternative technology, hypochlorite dissolution, were not considered, but since some plants are even now adopting this or similar technologies, it can be assumed to be cost-competitive.

The total investment over the 10-year period 1973-1983 for control of mercury emissions to land is an estimated $12 million, with annual operating costs of about $3.3 million.

Introduction of New Emission Control Technology

Reduction of mercury emissions by using the newer recovery techniques is not likely to occur suddenly. Some time will be required for the engineering design, construction, and bringing on-stream of the added facilities. It is estimated that, in general, three years would be a maximum time for these new recovery and control facilities to be put into operation. It is also probable that not all of the mercury-cell plants would undertake or complete the installation of such new facilities simultaneously.*

Figure 55 indicates the assumed rate of adoption of pollution control technology, and Table 44 summarizes the total cost of such technology and the total emissions, prorated in the manner shown in Figure 55. As can be seen from Table 44, over the 10-year period the total cost for control of emissions to each receiving environment is on the same order ($8 million to $12 million),

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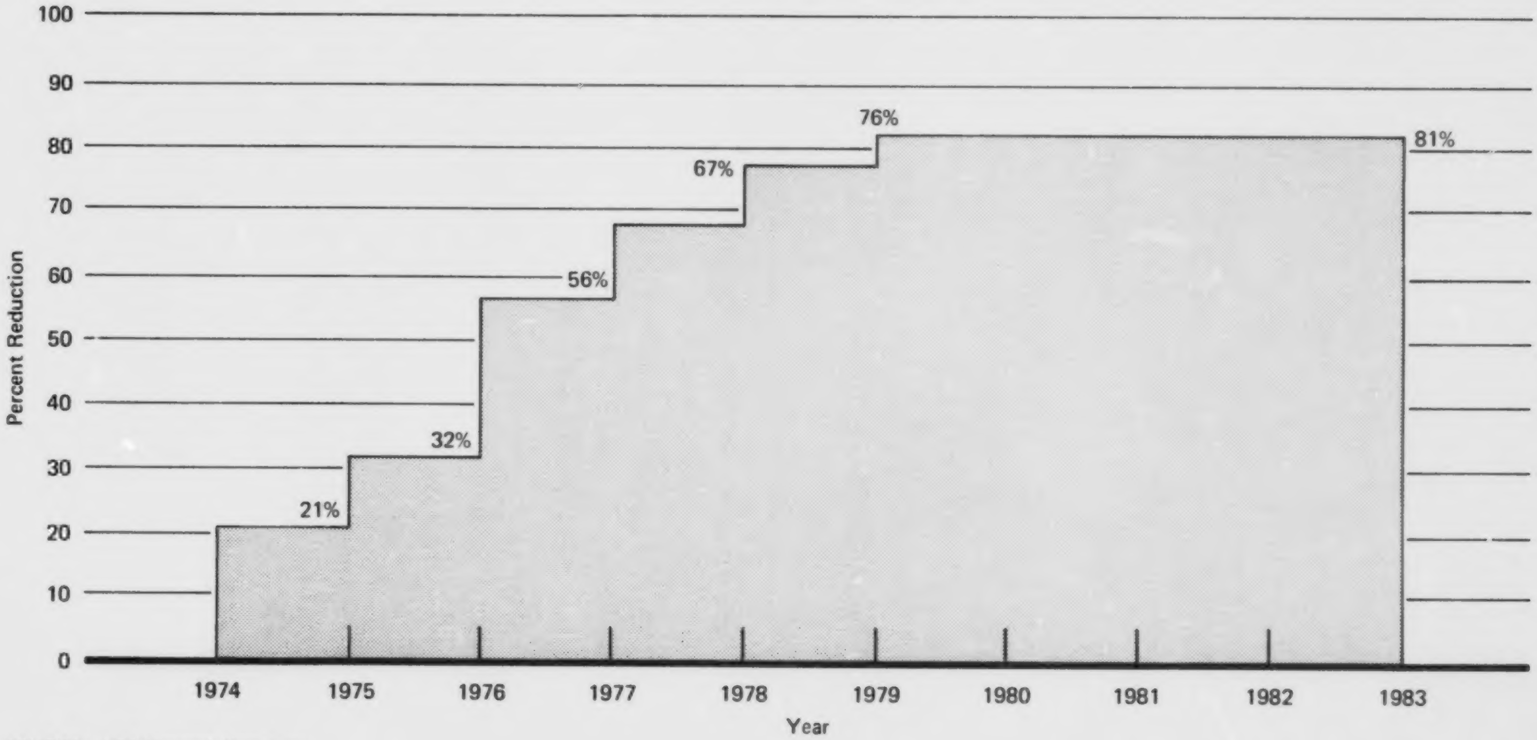
* Plants suffering the greatest losses would probably be the first to make the improvements. However, this is an assumption and cannot be proven before the fact. Many plants will not have to make additional investments in order to meet the projected average 1983 emission levels.



SOURCE: URS Research Company.

Figure 55 RATE OF INTRODUCTION OF POLLUTION CONTROL TECHNOLOGY

TABLE 44. - Emission Control Technology for Mercury Cell Chlor-Alkali Industry: Estimated Annual Cost and Emissions, 1973-1983

	Water			Land			Air			Total			
Year	Percent Reduction	Emissions (kg)	Capital Cost ($ x 10^6)	Percent Reduction	Emissions (kg)	Capital Cost ($ x 10^6)	Percent Reduction	Emissions (kg)	Capital Cost ($ x 10^6)	Year	Percent Reduction	Emissions (kg)	Capital Cost ($ x 10^6)
1973	0%	4,295	$ 0	0%	298,310	$ 0	0%	23,156	$ 0	1973	0%	325,761	$ 0
1974	20	3,436	2.26	22	232,682	3.47	11	20,610	2.42	1974	21	256,728	8.15
1975	38	2,663	4.47	37	187,935	5.72	18	18,988	4.54	1975	36	209,586	14.73
1976	54	1,976	6.34	54	137,223	8.32	27	16,904	6.24	1976	52	156,103	20.90
1977	68	1,374	8.07	64	107,392	9.81	32	15,746	7.50	1977	62	124,512	25.38
1978	80	859	9.51	73	80,544	11.29	36	14,820	7.94	1978	70	96,223	28.74
1979	90	430	9.85	78	66,362	11.98	38	14,357	8.30	1979	75	81,149	30.13
1980	94	250	10.10	78	66,362	11.98	40	13,894	8.60	1980	75	80,506	30.68
1981	94	250	10.10	78	66,362	11.98	40	13,894	8.60	1981	75	80,506	30.68
1982	94	250	10.10	78	66,362	11.98	40	13,894	8.60	1982	75	80,506	30.68
1983	94	250	10.10	78	66,362	11.98	40	13,894	8.60	1983	75	80,506	30.68
Annual Operating Cost		$1,500,000			$3,300,000			$2,600,000				$7,400,000	

Source: URS Research Company

but greatest overall reductions are achieved for water (94 percent) and the least for air (40 percent). However, the extent of reduction is of less importance, overall, than are the absolute quantities involved. Thus the total quantity of mercury discharged to air drops from some 23,156 kg in 1973 to 13,894 kg in 1983; this represents a decrease in the air burden of almost 10,000 kg. On the other hand, the absolute decrease in emissions between 1973 and 1983 with respect to water is less--about 4,000 kg--but of course their removal from receiving waters is an important contribution (note that further decrease of emissions to water is most unlikely, and probably most unnecessary).

Emissions to land, while not of serious concern as far as exposure to man and his environment are concerned (at least in the short term), are reduced significantly (78 percent) with an absolute value of more than 230,000 kg "saved."* In terms of cost-effectiveness the industry gains most, dollar-wise, by investing in control technology for its mercury-laden sludges. And because these sludges are removed from a repository which might eventually release their contents to the environment, the general public also benefits.

In Table 44 capital costs, although calculated on a year-to-year basis, are shown as cumulative, whereas operating costs are shown only on an annual basis. The omission of operating costs from the year-to-year values is acceptable because it is the capital equipment that is the more significant cost and the one which weighs heavily in management decisions.** The availability of internal capital resources and the cost of capital in external money markets also enter the picture. A calculation was made to assess the inflationary effects of two interest rates--6 percent and 10 percent (these rates consider the time value of money in constant dollars). At the expenditure rate indicated in Figure 55 and for the total cost of new emission control technology in current dollars ($30.7 million), the effective investment for the 6 percent rate at the end of the 10-year period is $48.7 million, and for the 10 percent rate it is $65.7 million.

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* A recent report (Ref. 60) projects that mercury cell solids will decrease from 270,000 kg in 1973 to 120,000 kg in 1978 and to 4,000 kg in 1983. This latter value, which is far below our estimate, appears to include effective treatment of high-level mercury solid wastes (the URS estimate considers such wastes as untreatable).

** Also, much of the new equipment represents an upgrading of present practices and this new equipment is very likely to be operated by little or no additional labor (a potential disbenefit).

The imposition of additional emission controls is seen by the industry as representing an investment of funds which does not contribute to productivity--or to profits. However, the savings of mercury recovered through control measures can offset some of the operating costs. Over the ten-year period considered, more than 2 million kg of mercury would be recovered; at a cost of $8.80/kg this amounts to almost $18 million dollars.

Cost-Benefit Analysis

Two practicable alternatives have been identified--conversion of mercury cell plants to diaphragm cell technology, and the reduction of emissions from present mercury cell plants by the imposition of stiffer emission controls. The cost-benefit results for these two alternatives are presented in Figure 56. The figure also includes a base case which assumes no growth within the industry and emissions continuing to meet present EPA standards. The benefit accrued is shown as the percent reduction in emissions of mercury to environment and the costs as total capital costs.*

Alternative 1, conversion to diaphragm technology over a 10-year period, ultimately produces the maximum benefit--100 percent reduction in mercury emissions. However, the associated cost of more than $600 million is clearly of a magnitude that would have major impact on money markets, to say nothing of the effects on corporate growth.

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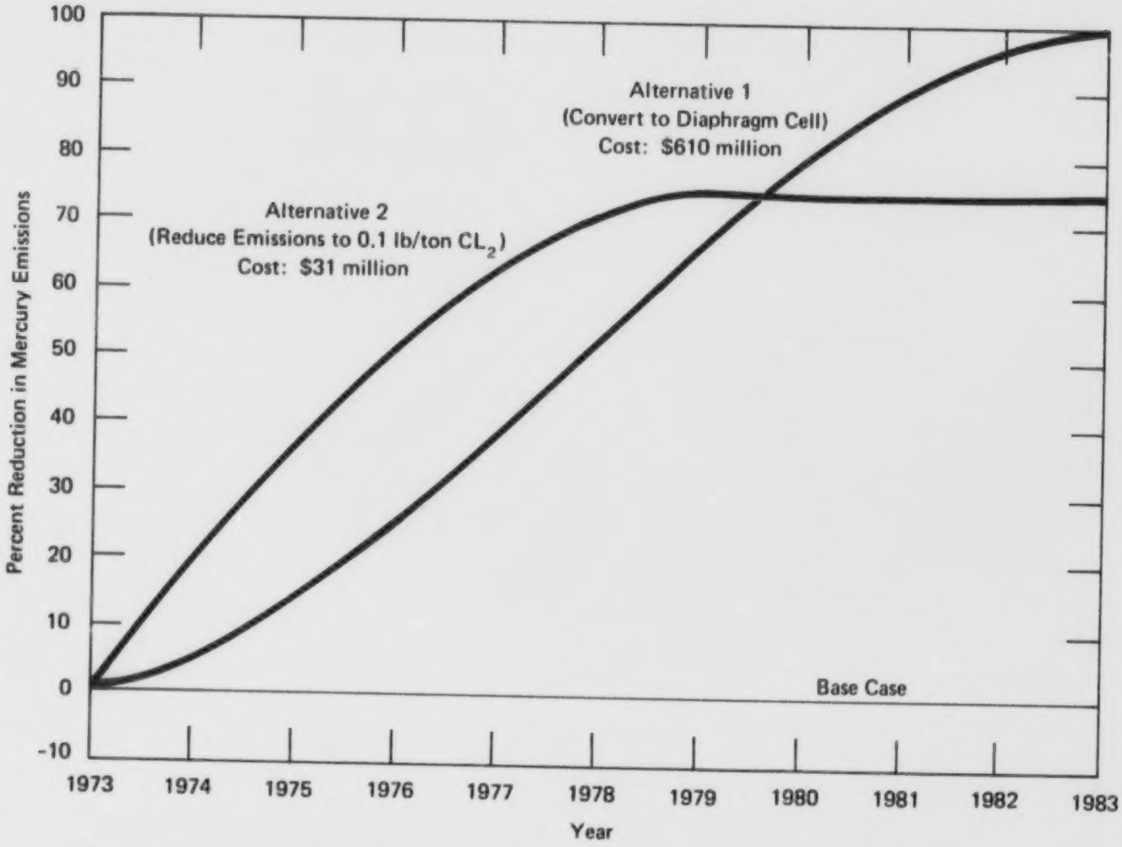
* It must be recognized that capital costs do not necessarily equate with social costs. For example, if the capital costs can be absorbed through higher prices (a common occurrence), the "cost" will only appear at the consumer's end, probably magnified--appearing as a reduction of prior consumer surpluses (also known as "foregone benefits"). If the consumer is unwilling to pay for these nonproductive investments, several other cost effects might occur, including plant closures and resultant unemployment; lower net income; or no plant expansion and a resultant constriction of supply.



SOURCE: URS Research Company.

Figure 56 TIME-PHASED REDUCTION OF MERCURY EMISSIONS FROM MERCURY CELL CHLOR-ALKALI PLANTS, AND ASSOCIATED COSTS

The second alternative can be effected more rapidly, since it represents only a minor modification of an existing structure, at a cost which can probably be assimilated easily (if not willingly). However, even with this vastly improved control over emissions of mercury, the residual losses (primarily to land and air), would still be significant, and pressure might continue for the removal of even these amounts.

A third alternative (not shown) is likely if pressures for control continue. This alternative involves the gradual phasing out of mercury cell plants, starting with marginal plants which cannot economically justify the cost of higher level emission control technology and/or which cannot compete with chlor-alkali produced in diaphragm cells.* To some extent this third alternative is in effect even now, since all new expansions in chlor-alkali are in diaphragm cell technology. However, any effort to force too short a time frame on this third alternative could have serious consequences for the industry and its customers. But if reasonable latitude is allowed in recovering investment on existing plants, the impact on the industry should be minimal.

Risk Assessment

Alternative 2, increased use of emission control technology, has no foreseeable risks associated with its adoption. But Alternative 1, conversion to diaphragm cell technology, does carry risks, since diaphragm cells are in themselves a source of toxic pollutants. Reference 60 estimates that chlor-alkali plants using diaphragm cell technology will produce solid wastes as follows:

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* The competitive advantage of one type of cell over the other is not clear and appears to depend heavily upon utility costs and the type of product required. Also, advances in the efficiency of the diaphragm (both in terms of electrical efficiency and the concentration of the caustic produced) may give it an even better competitive advantage. Even so, mercury cell technology may still be the obvious choice for plants where steam costs are prohibitive, or where customers require salt-free caustic, and so on.

	Thousands of Kilograms	
Year	Asbestos	Lead
1973	2,300	980
1978	3,800	900
1983	2,000	490

If mercury cell production of chlorine accounted for 20 percent of total production by 1983, complete conversion to diaphragm cells would apparently add 400,000 kg of asbestos and 98,000 kg of lead to these solid waste totals. However, new technology in diaphragm cells is eliminating the use of asbestos diaphragms and reducing the reliance on lead. Hence the additional waste load could be rather small. (As an aside, it is interesting that discharges from the diaphragm cell technology are decreasing less rapidly than those from mercury cell technology, even accounting for the growth of the diaphragm cell technology. The difference, we suspect, has to do with the value of the recovered waste; neither asbestos or lead has sufficient value to spur its recovery, but mercury does.)

Emissions from mercury cell chlor-alkali plants to water and air are of most concern, since these can directly affect the surrounding environment. Therefore, we made an estimate of the population which might be affected by such discharges. We determined the resident population (using 1970 Census data) within a 5-mile radius of each of the 28 mercury cell chlor-alkali plants (a total of 8,029,000 persons) and then estimated per capita emissions as follows:

Year	Kilograms	Milligrams per Capita
1973	14,910	1.86
1974	12,007	1.50
1975	9,361	1.17
1976	7,195	0.89
1977	4,948	0.62
1978	3,567	0.44
1979	3,131	0.39
1980	2,973	0.37
1981	2,973	0.37
1982	2,973	0.37
1983	2,973	0.37

The per capita emission factor (primarily from final consumption of mercury-containing products) amounts to 2.185 mg/person for air and water combined. Thus the 1973 emissions of 1.86 mg/person from the chlor-alkali plants do impose an appreciable added burden on the affected 8 million population. However, with reduction of chlor-alkali emissions to a projected value of 0.37 mg/person by 1983, the added burden would be only 17 percent, and is of less concern.

REGULATION IN THE PAINT INDUSTRY

The use of mercurials in the paint industry is largely confined to water-based product manufacture. The scope of this analysis, accordingly, is limited to two product groups: exterior water-type paint products and tinting bases (SIC 28512) and interior water-type paint products and tinting bases (SIC 28514).

Figure 57 relates mercury to its host economic process, exterior and interior latex paint manufacture. In terms of product flow, the integration of this element into the paint manufacturing sequence may be viewed in five distinct stages.

1. Production. Approximately 7,600 flasks of mercury were produced during 1973 for use in water-based paint manufacture. This represents about 14 percent of the total 1973 mercury supply. Since only a small portion of the U.S. supply derives from domestic mining operations, it can be safely assumed that a similarly small U.S. mining revenue (perhaps $100,000 in 1973) generates from paint-related requirements, and that very little mining employment (perhaps the equivalent of 10 to 15 workers) is paint-dependent.

2. Process. Before it is incorporated in water-based paint, mercury is subjected to an intermediate process. It is converted into phenylmercuric acetate (PMA)* for use as a preservative and mildewcide. Approximately one million pounds of PMA were processed from mercury during 1973 for use in paint manufacturing. The related value realized by the PMA industry is estimated as $13 million to $14 million. Related employment may range from 200 to 250 workers.

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* Other types of phenylmercurics are less commonly used, but the differences are of no importance in this analysis.

3. Paint Manufacture. Mercury, reconstituted as PMA, contributes to the manufacture of water-based interior and exterior paints. Approximately 260 million gallons of these paint products were produced in 1973. Mercury (as PMA) therefore contributed to the generation of nearly $1 billion in revenues and to employment support for approximately 15,000 workers.

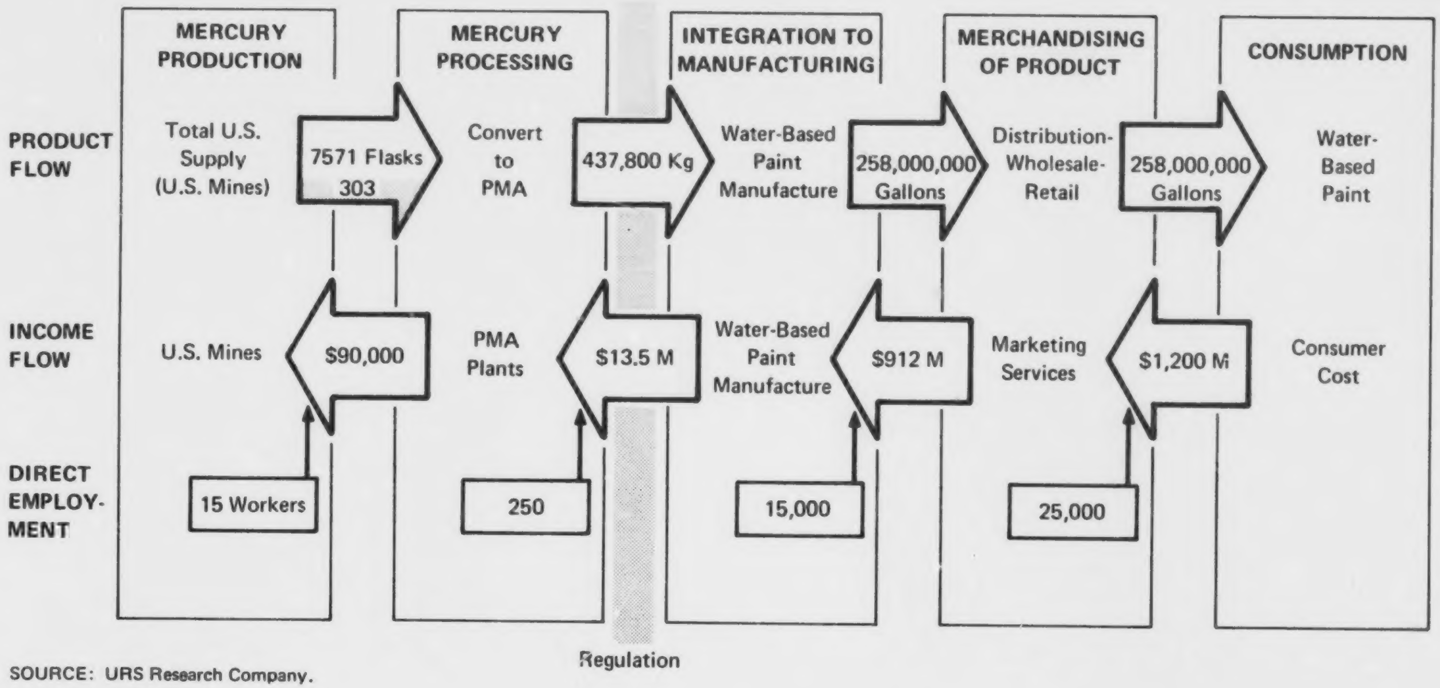
4. Paint Distribution and Marketing. The distribution and marketing of mercury-bearing paints occupies another economic sector. Wholesaling and retailing functions are intermediate between the manufacturing process and the consumer. Following the same 260 million gallons of water-based paint through this activity reveals total revenues of $1.2 billion in 1973, and an implied associated employment of perhaps 25,000.

5. Consumption. U.S. consumers, through their demand for latex paints or for products or services which require such paints, stimulated the production and provision of the 260 million gallons of water-based paints in 1973. Consequently, consumers ultimately had to pay the bill. This bill may be disguised by the indirect channels through which it reaches the individual consumer (for instance as a component of furniture cost, or housing cost, or of his government tax bill), but eventually the entire revenue flow--from $1.2 billion in final product cost to $100,000 in mercury mining revenues—will generate from the individual consumers.

Regulatory Alternatives and Effects

For purposes of this analysis, only one regulatory option is examined: the staged (phased) elimination of all mercury use in water-based paint manufacture. The analysis assumes the accomplishment of the transition to substitute technology within five years. This regulating policy is examined relative to a theoretical base condition defined as "no regulation."

Mercury regulation would have the effect of cutting off the flow of a significant ingredient, PMA, in the water-based paint manufacturing process. In Figure 57, a barrier may be visualized midstream in the product flow diagram. Two consequences are immediately apparent. First, all product flow, revenue, and employment that previously were realized behind that regulatory screen will


MERCURY PRODUCTION
MERCURY PROCESSING
INTEGRATION TO MANUFACTURING
MERCHANDISING OF PRODUCT
CONSUMPTION
PRODUCT FLOW
Total U.S. Supply (U.S. Mines)
7571 Flasks 303
Convert to PMA
437,800 Kg
Water-Based Paint Manufacture
258,000,000 Gallons
Distribution-Wholesale-Retail
258,000,000 Gallons
Water-Based Paint
INCOME FLOW
U.S. Mines
$90,000
PMA Plants
$13.5 M
Water-Based Paint Manufacture
$912 M
Marketing Services
$1,200 M
Consumer Cost
DIRECT EMPLOY-MENT
15 Workers
250
15,000
25,000
Regulation

SOURCE: URS Research Company.

Figure 57 PRODUCT AND INCOME FLOW FOR THE PRODUCTION AND CONSUMPTION OF MERCURY-CONTAINING PAINTS

be jeopardized. Second, if product supply is to be maintained, substitutes for the regulated ingredient must be incorporated into the process.

As stated earlier, the mercury production and processing aspects of water-based paint manufacture generated total revenues in excess of $13 million and total paint-related employment of perhaps 265. Table 45 indicates the scale of product, income, and employment that would attend a base-case condition expanded at a 5 percent rate of growth between 1973 and 1983.

The elimination of mercury and mercury-dependent processes from the paint industry might eventually threaten the jobs of 430 workers and a business income of approximately $22 million per year. Under worst-case circumstances and within a very narrow frame of reference, this may in fact reflect some small part of the industry's future.

In a broader sense, though, other compensatory changes will be created by these disruptions. Some PMA plants, together with their revenue and employment bases, will be preserved by accomplishing the transition to substitute processes. In addition, a major new domestic industry--that of substitute process--will be catalyzed around them.

Few secure predictions can be made regarding the development of a substitute process industry and its incorporation into the water-based paint industry. Recent substitute technology experience, however, indicates several areas of potential impact:

o Increase in Manufacturing Cost/Product Price. Paint industry representatives estimate that the utilization of current mercurial substitutes would result in increases ranging from $0.15 to $0.25 per gallon in manufacturers' product prices. Retail prices may increase $0.60 to $1.20 per gallon.

o Degradation in Product Quality. Tests of the service life of water-soluble paints containing substitutes for PMA indicate potentially significant reductions in paint permanence.

o Market Ramifications. The demand characteristics of the American paint consumer have been relatively stable over the last 10 years. Figure 58 portrays the historic pattern of consumer demand behavior in the face of price levels. For purposes of comparison, approximately 10 years of monthly price/supply relationships were calculated and normalized to 1973 market proportions and

TABLE 45. - Estimated Product and Income Flow for Production and Consumption of Paints Containing Mercury, 1973-1983: Base (No Regulation) Case[a]

A. Product Flow

Year	Total Supply (flasks)	Process (000 lbs)	Mfg. (000 gal)	Retail/Wholesale (000 gal)
1973	7,571[b]	965.4	258,000.0	258,000.0
1978	9,663[b]	1,232.1	329,285.4	329,285.4
1983	12,333[b]	1,572.5	420,267.0	420,267.0

B. Income Flow (thousands of 1973 dollars)

Year	U.S. Mine Production	Related Process (PMA)	Related Mfg.	Related Retail/Wholesale
1973	$ 90.0	$13,500.0	$ 912,000.0	$1,200,000.0
1978	114.9	17,230.1	1,163,985.6	1,531,560.0
1983	146.6	21,990.7	1,485,594.8	1,954,730.0

C. Related Employment (number of workers)

Year	U.S. Mine Production	Related Process (PMA)	Related Mfg.	Related Retail/Wholesale
1973	15	250	15,000	25,000
1978	19	319	19,145	31,908
1983	24	407	24,434	40,724

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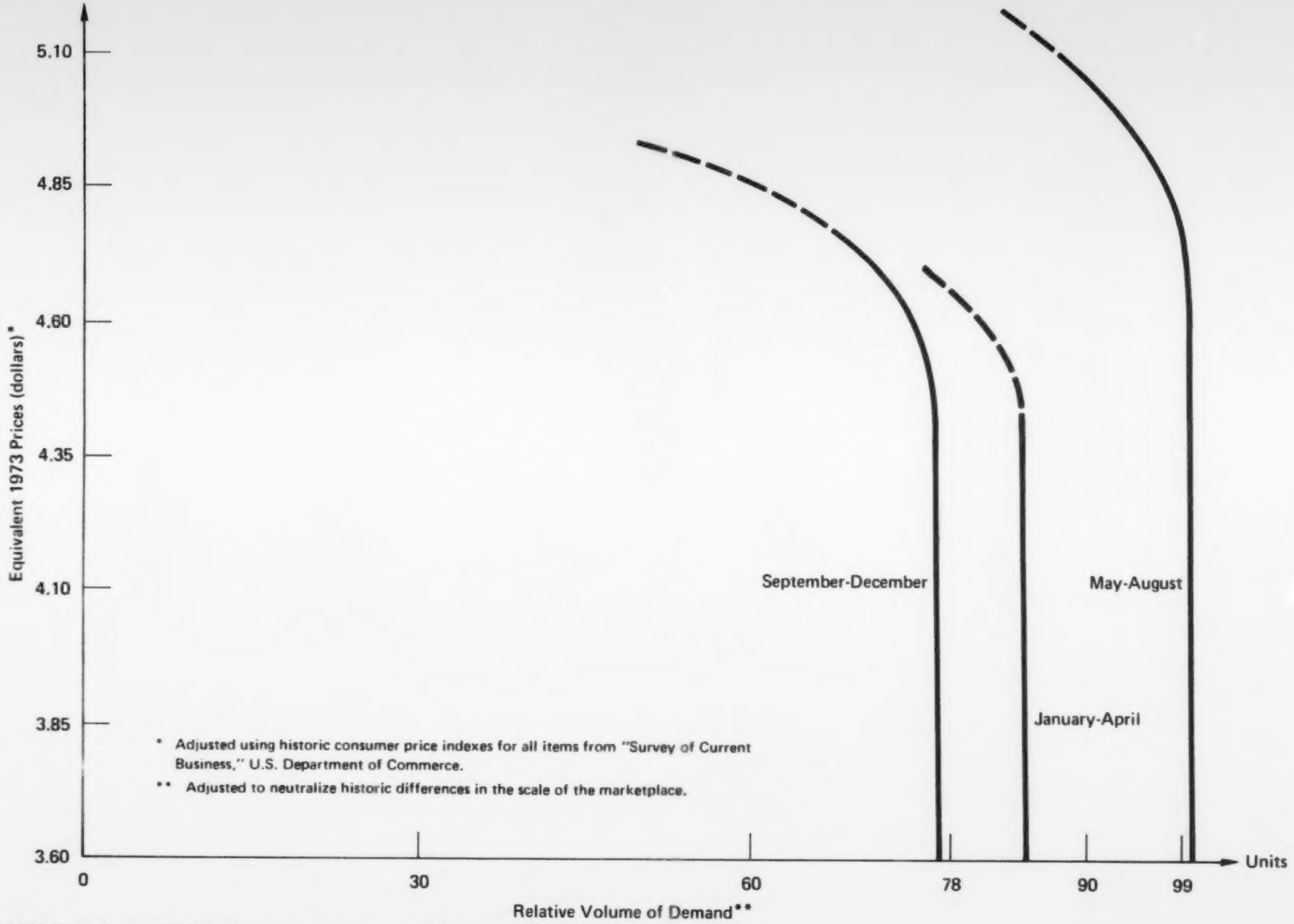
a. Assumes a growth rate of 5 percent per year.

b. This total includes foreign and domestic sources. U.S. mines contributed only 4 percent.

Source: URS Research Company



* Adjusted using historic consumer price indexes for all items from "Survey of Current Business," U.S. Department of Commerce.

** Adjusted to neutralize historic differences in the scale of the marketplace.

SOURCE: Derived by URS Research Company from data in "Current Industrial Reports; Volume and Sales of Paint and Varnish," 1964-1974.

Figure 58 PRICE ELASTICITY OF DEMAND IN THE PAINT INDUSTRY

1973 dollar values. As shown, the consumer's price thresholds vary with the seasons: during the summer he will tolerate price changes of up to 25 percent before his demands will shift; during the fall/winter period his demands are naturally lower but his willingness to accommodate price changes is also reduced--perhaps to 15 percent; during winter/spring his demands are typically higher, but so is his willingness to tolerate price changes--down to 10 to 12 percent.

From these data it would appear that demand for paint products may be adversely affected by imposed substitutes, particularly in off-peak seasons.

It is ironic that another adverse quality of mercurial substitution--shortened product service life--may (at least as far as the industry is concerned) serve to offset the price-stimulated contraction of demand. It remains to be seen, though, whether the consumer's desire for equal product service can be reconciled with his limited disposable income and his reluctance to surrender other valued goods and services. As of this moment there are not enough behavioral precedents to enable quantification of this aspect of consumer behavior.

Table 46 estimates the income and employment consequences of a transition from current mercurial processes to substitute technology. The higher cost of mercurial substitutes results in significantly greater income to the process industry in general, and through the effects of marginal pricing also results in greater income to the activities that follow manufacturing. Employment is expected to be tripled by 1983 from the base case within the process industry (from about 400 for the PMA process to more than 1,200 for substitute processes), while remaining essentially unchanged in related manufacturing and merchandising. These gains are both small (relative to the industry that surrounds them) and highly tentative until the price-pull, quality-push forces on consumer demand are resolved. The estimated 1983 price per gallon penetrates the $5.10 per gallon (1973 dollars) threshold beyond which demand diminution has historically been experienced. To place this threat in perspective, a 10-percent contraction in demand in 1983 would jeopardize the jobs of more than 6,000 industry workers.

By way of summary, Figure 59 graphically displays these various effects in net terms. Relative to the baseline condition detailed in Table 45, mercury

TABLE 46. - Estimated Income and Employment Consequences of a Shift to Substitutes for Mercury in Paint Manufacture and Use

A. Income Flow (thousands of 1973 dollars)

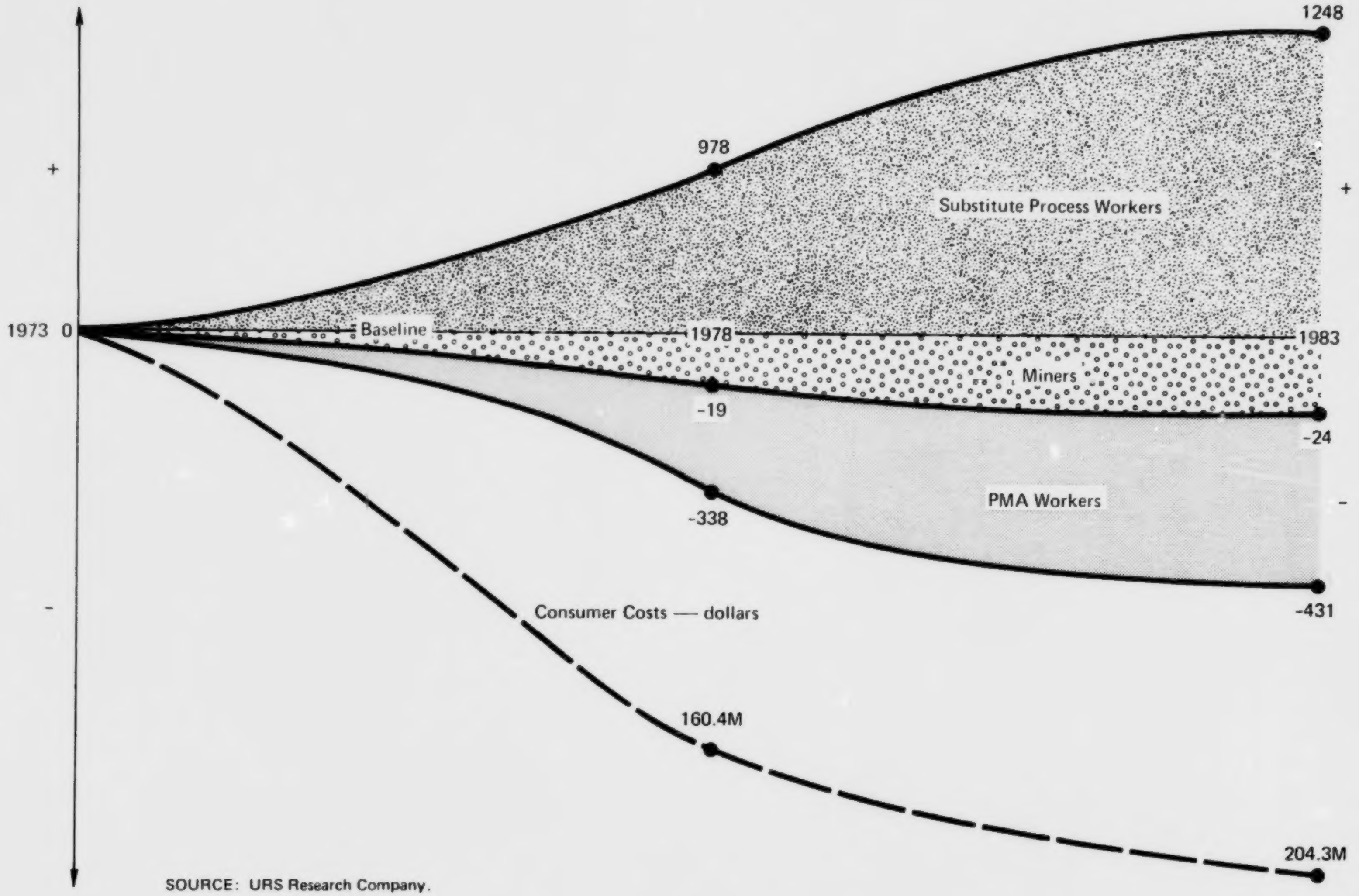
Year	U.S. Mine Production	Related Processes PMA	Related Processes Substitute[a]	Related Mfg.	Related Retail/Wholesale
1973	$90.0	$13,500.0	$ --	$ 912,000.0	$1,200,000.0
1978	--	--	83,090.0	1,253,100.0[b]	1,691,980.0[c]
1983	--	--	106,050.0	1,539.135.0[b]	2,159,063.0[c]

B. Employment (number of workers)

Year	U.S. Mine Production	Related Process PMA	Related Process Substitute[a]	Related Mgf.	Related Retail/Wholesale
1973	15	250	--	15,000	25,000
1978	--	--	978[d]	19,145	31,908
1983	--	--	1,248[d]	24,434	40,724

a. Assuming substitute price 20 cents/gallon above PMA.
b. Assuming maintenance at an operating margin of 35 percent.
c. Assuming that the collective margin requirement with the merchandising chain will approximate 80 percent.
d. Assumes an average value per worker of $85,000 per year.

Source: URS Research Company



SOURCE: URS Research Company.

Figure 59 CONSUMER AND MANUFACTURING COSTS ASSOCIATED WITH THE REMOVAL OF MERCURY FROM PAINT

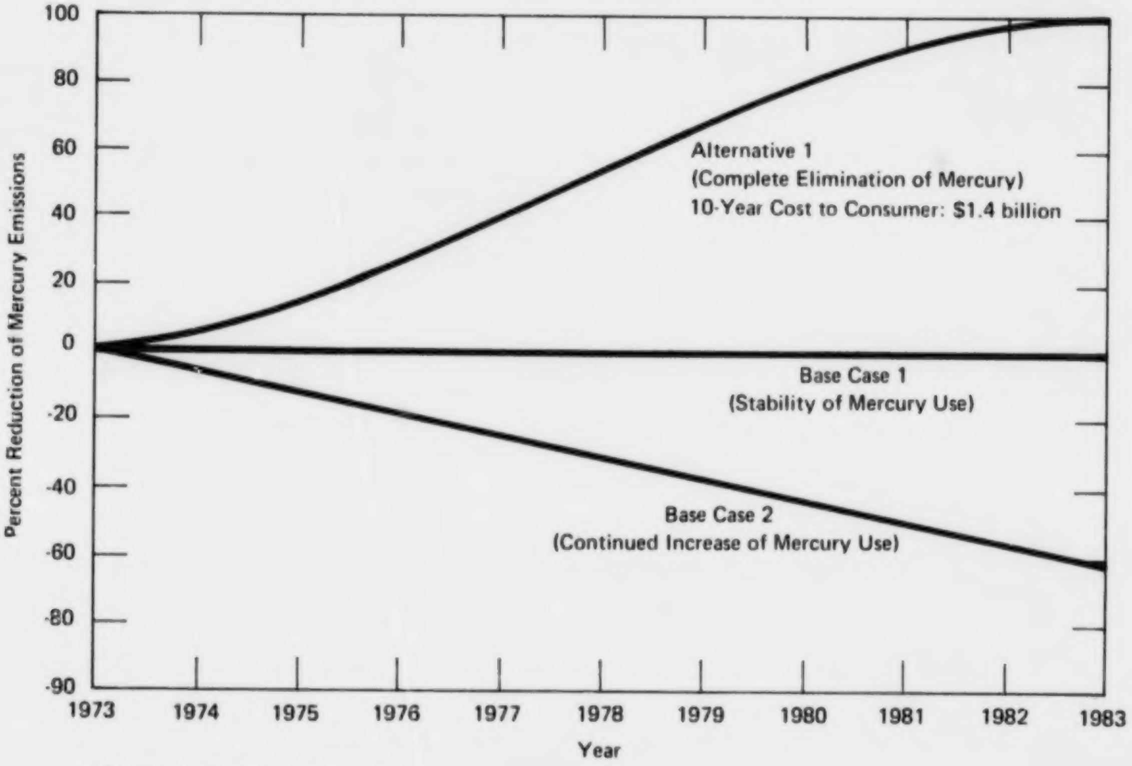
regulation can be seen to impose negative consequences upon mercury miners and PMA plant workers but at the same time to make a positive contribution in terms of substitute technology employment. Ultimately, though, the consumer will incur the largest unrelieved disbenefit. By 1978, if mercury substitutes are adopted, consumers will have spent $160 million more, for products that may yet be inferior in service value, than would be true for mercury-containing paints. By 1983, this annual net cost (loss of prior consumer surplus or "foregone benefit") would amount to more than $200 million.

Cost-Benefit Analysis

One alternative--the elimination of mercury from paint--and two base cases have been considered. Base case 1 assumes that mercury usage in water-based paints will remain constant despite a forecast growth in paint sales; that is, all new market growth will be for substitutes. Base case 2 assumes that mercury use will grow at the same rate as total paint sales. These three curves are shown in Figure 60, which indicates the percent reductions (or increases) in mercury emissions over time. No costs are assigned to the base cases, and only costs to the consumer are assigned to the alternate. (As noted in the previous discussion the elimination of mercury from paint will cause some redistribution of revenues within the mining, manufacturing, and final consumption sectors, but the net change will be an increase in the total number of workers in the associated industries.) These consumer costs are estimated to amount to more than $1.4 billion over the 1973-1983 period. (This is reflected as an additional constant-dollar cost of 50 cents per gallon to the consumer by 1983.) The benefit, of course, is the elimination of paint as a source of mercury emissions to the environment--a source that discharged some 183,000 kg of mercury in 1973 alone.

Risk Assessment

No risks associated with the elimination of mercury from paint have been quantified, but some possible risks which merit further consideration have been noted. The materials used in place of the mercurials in paint are, of themselves,



SOURCE: URS Research Company.

Figure 60 TIME-PHASED REDUCTION IN MERCURY LOSSES FROM PAINT USAGE, AND ASSOCIATED COSTS

toxic to a degree, but unlike mercurials they do not appear to migrate from the painted surface to air. The introduction of these mercurial substitutes into receiving waters is undesirable, but as shown by our inventory results, the amount of paint that enters sewers is small. Dermatitis resulting from the use of latex paints containing mercurial substitutes has been reported by some persons, but the extent of the problem is rather limited.

Some representatives of the paint industry report the growth of *Pseudomonas* species on walls painted with nonmercurial, water-based paints. They suggest that such growth could have serious consequences in some settings, such as hospitals. However, confirmed instances have not been recorded.

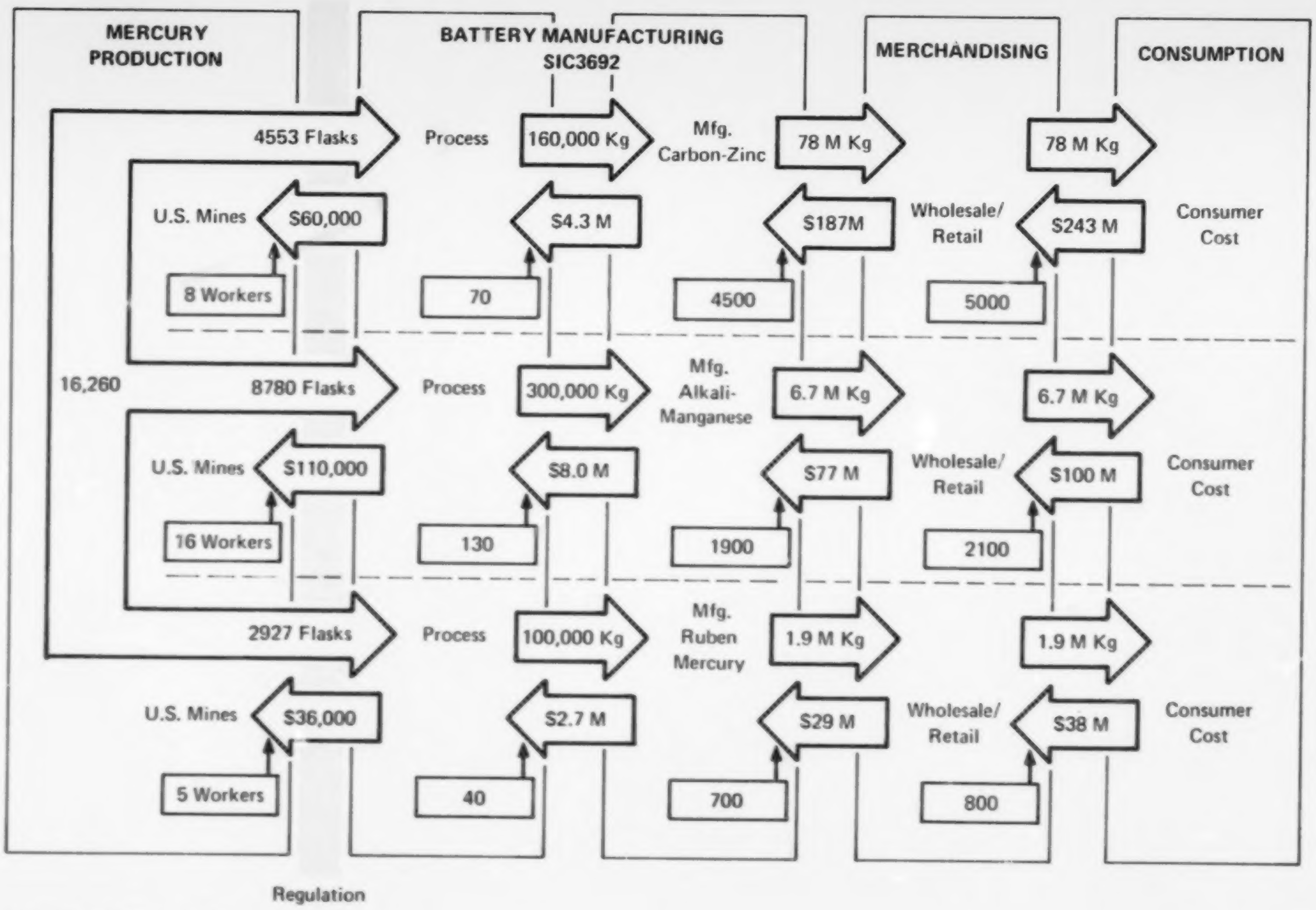
Virtually all loss of mercury associated with paint occurs soon after the paint is applied, and these losses are almost entirely to air. Concentrations can be high during and immediately following painting, but the consequences, if any, do not appear to concern the general population, whose frequency of exposure to newly painted rooms is undoubtedly low. However, we can compare the per capita emission to air with the per capita values for paint alone. The first value is 1.80 mg/person/year; the emissions to air from paint usage account for 0.87 mg/person/year--roughly half of the first value.

REGULATION IN THE BATTERY INDUSTRY

The use of mercury in the battery industry centers in three product areas: zinc-carbon, alkaline-manganese dioxide, and Ruben mercury batteries. Collectively, these manufacturing activities required 30 percent of the mercury used in the United States in 1973. The larger industry group from which these products derive is SIC 3692, Primary Batteries, Dry and Wet.

Figure 61 relates mercury to these three principal product manufacturing processes. Mercury can be traced from its source of supply or production to its terminus (consumption) in five developmental stages.

1. *Mercury Production*. Approximately 16,260 flasks of mercury were produced by domestic and foreign suppliers for use in battery manufacture in 1973. Only a small fraction of that supply was developed from then-current domestic mining operations. Indeed, U.S. producers contributed only 4 percent


MERCURY PRODUCTION
BATTERY MANUFACTURING SIC3692
MERCHANDISING
CONSUMPTION
4553 Flasks
Process
160,000 Kg
Mfg. Carbon-Zinc
78 M Kg
78 M Kg
U.S. Mines
$60,000
$4.3 M
$187M
Wholesale/ Retail
$243 M
Consumer Cost
8 Workers
70
4500
5000
16,260
8780 Flasks
Process
300,000 Kg
Mfg. Alkali-Manganese
6.7 M Kg
6.7 M Kg
U.S. Mines
$110,000
$8.0 M
$77 M
Wholesale/ Retail
$100 M
Consumer Cost
16 Workers
130
1900
2100
2927 Flasks
Process
100,000 Kg
Mfg. Ruben Mercury
1.9 M Kg
1.9 M Kg
U.S. Mines
$36,000
$2.7 M
$29 M
Wholesale/ Retail
$38 M
Consumer Cost
5 Workers
40
700
800
Regulation

SOURCE: URS Research Company.

Figure 61 PRODUCT AND INCOME FLOW FOR THE PRODUCTION AND CONSUMPTION OF MERCURY-CONTAINING BATTERIES

to the total U.S. supply in 1973. Therefore, although approximately $5 million was spent for mercury by the battery industry in that year, only slightly more than $200,000 accrued to U.S. entrepreneurs and workers. Battery-associated mining employment was probably in the range of 30 persons.

2. Processing. Most preliminary processing of mercury is accomplished within the vertically integrated structure of the battery industry itself. Processing, though legally invisible, may be statistically approximated. The scale of this activity is of significance to this analysis.

- o Carbon-zinc battery manufacture requires the processing of approximately 160,000 kg of mercury. Employment for this purpose may be 70 persons.
- o Alkaline-manganese dioxide battery manufacture requires approximately 300,000 kg of mercury and provides support for perhaps 130 workers.
- o Ruben mercury cell manufacture requires approximately 100,000 kg of mercury and occupies approximately 40 workers.

3. Manufacture. Mercury contributes to the production of almost 85 million kg of carbon-zinc, alkaline-manganese, and Ruben mercury cells. Collectively these batteries represent an economic value of nearly $300 million at producers' prices. Almost 7,000 workers derive their support from the manufacture of these types of cells.

4. Merchandising. Distribution, wholesaling, and retailing activities related to these products generate almost $400 million in revenues and support for approximately 8,000 workers.

5. Consumption. Once again, it is the consumer who must generate the $400 million product need that will initiate the entire transaction sequence.

Industry Regulation

Research and development activity has yet to produce a satisfactory replacement for mercury in electrical applications. As of now, therefore, only recycling is envisioned as a viable regulatory goal. This analysis, accordingly, assumes that regulations will have the effect of constricting the flow of virgin mercury into battery manufacturing processes and of replacing that flow with recycled material previously lost to landfill and incineration. A possible alternative, the imposition of regulations on disposal of mercury-containing solid wastes at the final disposal site, was rejected as too cumbersome and not amenable to analysis.

Relative to a base case of "no regulation," a recycle regulation would serve to diminish the support capacity of mining operations allied to the battery industry and, second, would encourage the development of new support capacity in the battery recycling industry. In order to judge the potential socioeconomic effects of this economic redistribution, the product, income, and employment accounts of Figure 61 were extrapolated using differential growth rates. Carbon-zinc battery manufacture was assumed to increase at a rate of 5.3 percent per year. Alkaline-manganese cell manufacture was assumed to grow at a rate of 12.8 percent per year. Ruben mercury battery production was assumed to increase at a rate of 7 percent per year. Table 47 shows the product, income, and employment projections that result.

As indicated, recycling regulations would threaten the jobs of perhaps 70 U.S. mercury mine workers in 1985. Beyond that, recycling will serve to reduce our dependence on mercury imports and thereby improve our balance of trade. Such regulations will also foster the growth of improved scrap recovery, reprocessing, and reuse technology. A result of this process will undoubtedly be higher mercury materials cost to the battery industry, at least in the near term. The ultimate implication of such higher costs, naturally, is higher consumer prices. Although no cost or price impact can be estimated at this stage, some interval approximations may be advanced.*

A. 10 Percent Recovery: 10 Percent Higher Input Cost

- Carbon-zinc. Recovery of 16,000 kg in 1973 to 27,000 kg in 1983 (at $9.70/kg). The total consumer price impact might approach $60,000 in 1973 and $100,000 in 1983.
- Alkaline-manganese. Recovery of 30,000 kg in 1973 with a price impact of $100,000 and 101,000 kg in 1983 with a price impact of $333,500.

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* For these estimates the values given for 1973 represent a potential for recovery. Similarly, this analysis assumes that the technology for recovery of the mercury content of carbon-zinc and alkaline-manganese batteries is now available, but such is not the case. Modification of current retorting practices would probably suffice for the recovery of mercury from alkaline-manganese batteries, but suitable technology would have to be developed for carbon-zinc batteries.

TABLE 47. - Estimated Product and Income Flow for Production and Consumption of Batteries Containing Mercury 1973-1983

A. Product Flow

Year	Mercury Supply (no. of flasks)	Thousands of Kilograms Process	Mfg.[a]	Merchandising[a]
		Carbon-Zinc		
1973	4,606	160.1	78,000.0	78,000.0
1978	5,927	207.1	100,980.0	100,980.0
1983	7,673	268.2	130,727.2	130,727.2
		Alkaline-Manganese Dioxide		
1973	8,805	300.0	6,700.0	6,700.0
1978	16,124	548.0	12,236.0	12,236.0
1983	29,445	1000.5	22,344.5	22,344.5
		Ruben Mercury		
1973	2,349	100.0	1,900.0	1,900.0
1978	4,128	140.3	2,665.0	2,665.0
1983	5,790	196.7	3,737.8	3,737.8

TABLE 47. - Estimated Product and Income Flow for Production and Consumption of Batteries Containing Mercury 1973-1983 (continued)

B. Income Flow (thousands of 1973 dollars)

Carbon-Zinc

Year	U.S. Mine Production	Process	Mfg.	Merchandising
1973	$ 60.0	$ 4,300.0	$187,000.0	$243,000.0
1978	77.7	5,566.8	242,000.0	314,600.0
1983	100.6	7,206.8	313,409.9	407,300.0
		Alkaline-Manganese Dioxide		
1973	110.0	8,000.0	77,000.0	100,000.0
1978	200.0	14,600.0	140,600.0	182,600.0
1983	367.0	26,700.0	256,800.0	333,500.0
		Ruben Mercury		
1973	36.0	2,700.0	29,000.0	38,000.0
1978	50.0	3,787.0	40,700.0	53,300.0
1983	70.8	5,311.6	57,050.0	74,800.0

TABLE 47. - Estimated Product and Income Flow for Production and Consumption of Batteries Containing Mercury
1973-1983
(continued)

C. Employment (number of workers)

Year	U.S. Mine Production	Process	Mfg.	Merchandising
		Carbon-Zinc		
1973	6	70	4,500	5,000
1978	8	91	5,800	6,500
1983	10	117	7,500	8,400
		Alkaline-Manganese Dioxide		
1973	16	130	1,900	2,100
1978	29	237	3,470	3,935
1983	53	434	6,337	7,004
		Ruben Mercury		
1973	5	40	700	800
19	7	56	982	1,122
1983	10	79	1,377	1,574

a. Total weight of batteries produced

Source: URS Research Company

- Ruben mercury. Recovery of 10,100 kg in 1973 with a net price effect of $35,000 and 20,000 kg in 1983 with a price impact of $70,000.

B. 10 Percent Recovery: 25 Percent Higher Costs

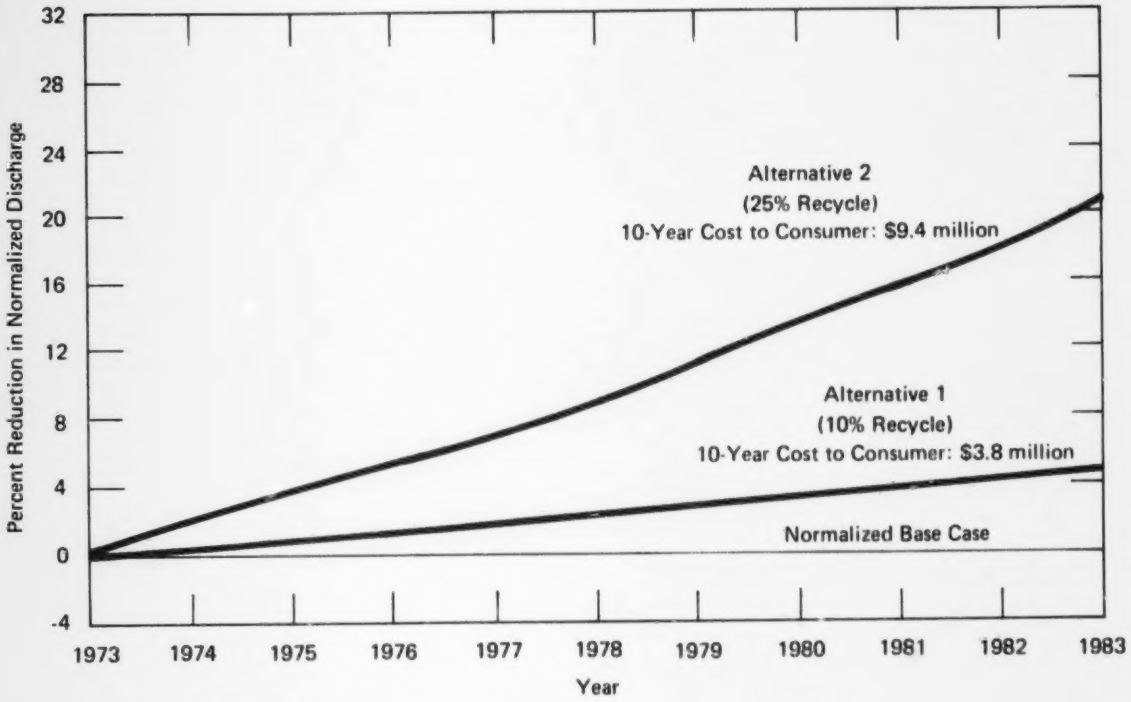
- Carbon-zinc. The price impact in 1973 would be $150,000 and in 1983 it would be $250,000.
- Alkaline-manganese. The price impact would be $250,000 in 1973 and $833,000 in 1983.
- Ruben mercury. The price impact in 1973 would be $87,500; the impact in 1983 would be $175,000.

C. 25 Percent Recovery: 10 Percent Higher Costs

- The net price impacts would be identical to those quantified under B.

Cost-Benefit Analysis

Because of the increased projected usage of mercury-containing batteries in the future, the base case projected for such batteries was found to result in an increase of 260 percent in the emissions of mercury to the environment over the next ten years. (Since the introduction of substitute batteries which could reduce reliance on mercury-containing batteries is unlikely, a base case which considered less spectacular growth could not be considered.) Because this increase masked any real benefits (that is, reductions in relative mercury usage), the base case was normalized, as shown in Figure 62, to a "no growth" base. Two alternatives were then plotted: 10 percent recycling with an attendant 10 percent cost increment based on the amount of recycling, and 25 percent recycling, with an attendant 10 percent cost increment based on the amount of recycling. Alternative 1, 10 percent recycling, reduces the discharge of mercury to the environment 5 percent over the base case by 1983. The total reduction for Alternative 1 for the 10-year period is about 4 percent over the base case and represents an absolute reduction in the amount of mercury lost of about 400,000 kg, with an attached cost to the consumer of $3.8 million.



SOURCE: URS Research Company.

Figure 62 TIME-PHASED REDUCTION IN MERCURY LOSSES FROM BATTERY RECYCLING, AND ASSOCIATED COSTS

Alternative 2, 25 percent recycling, reduces the discharge of mercury to the environment over the base case 22 percent by 1983. The total reduction for the 10-year period for this alternative is 15 percent over the base case, representing an absolute reduction in the amount of mercury lost of more than 1.4 million kg, with an attached cost to the consumer of $9.4 million.

The cost-effectiveness of these two alternatives was determined in terms of dollars (consumer costs) per kilogram of mercury removed (that is, reduced below that for the base case). For Alternative 1, the cost per kilogram is $9.47 for the 10-year period, and it is $6.55 for Alternative 2. However, by 1983 the initial recycling costs will have been largely absorbed, so that the cost, for 1983 only, is $7.21/kg for Alternative 1 and $4.06/kg for Alternative 2.

Risk Assessment

Recycling, which has been delineated as the only viable alternative, does not appear to have risks associated with its implementation. As has been discussed, recycling of mercury-containing products either by the battery manufacturer or by an independent agent will not involve any appreciable losses to the environment.

Of particular concern (although not specifically addressed in the previous discussion) is the diversion of mercury-containing solid wastes such as batteries from final disposal involving incineration. Some municipal incinerators have been reported as the source of unusually high discharges of mercury to air, and since these are usually located in urban areas, the stack discharge impinges on a large population. Control of these emissions from the stack is a possibility, but if the regulatory actions outlined above were properly designed, special attention would be paid to the recovery of mercury-containing solid wastes at recycling centers (a growing phenomenon), thereby reducing the quantities of such wastes that would be incinerated. Recycling might also involve a "grass roots" collection system, such as now operates for aluminum cans and newspapers, with a monetary incentive to enlist a large segment of the population to participate, possibly through recycling centers established and maintained by the battery industry (and other producers of mercury-containing solid wastes). No risks are involved with such schemes.

OVERVIEW

Viewed in a truly macro perspective and in the long term, regulatory policy decisions threaten "costs" not so much as they do new equilibrium. Unless regulatory policies alter the magnitude of total personal income in the United States or have some differential effect on foreign competition, the net effect of such policies will not be loss or gain but redistribution.

Thus, losses to the mercury mining industry will be offset by gains in other mineral development areas; losses in mercury processing will accrue gains to substitute processing activities; costs to the consumer in terms of higher prices (foregone benefits) will appear as revenue to producing industries and as salaries (realized benefits) to their labor forces.

At such a macro level, social judgments regarding such policy decisions may be distilled to a few philosophical considerations:

1. Regulations per se distort the "normal" market process; the natural allocation of goods and services is altered; consumer discretion is reduced; consumer values are imposed rather than elected.
2. Regulations "take" from one sector and "give" to another. Often the total of revenues or workers affected remain unchanged; however, the fact remains that otherwise employed workers are made unemployed and that previously income-rich regions may be made income-short in the process.
3. Regulations impose their effects on other activities than the targeted activities. The forced contraction of mercury-related industry will inevitably affect support industries which have previously provided materials or services and have indirectly realized mercury-related revenue and employment support. Thus, the magnitude of economic redistribution which

may be authored by regulatory policy is substantially underestimated by quantification of direct effects alone. Indirect effects may equal or exceed those anticipated within the regulated economic process.

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APPENDIXES

APPENDIX A

MERCURY IN THE ENVIRONMENT

Improper usage of organomercurials or their careless disposal has led to human suffering and death in Iraq, the United States, and Japan. These tragedies have forced the scientific and economic communities to examine the sources of mercury in the environment; the nature of the physical, chemical, and biological interactions involving mercury; mercury's environmental fate; and the effects on the biological community as mercury and its compounds cycle through the environment. This appendix reviews recent information in terms of the air, land, and water environments.

MERCURY AND THE AIR ENVIRONMENT

Sources

The air environment receives both natural and man-made inputs of mercury (see Fig. A-1). These inputs are shown in Table A-1, with typical emission and ambient air concentrations. The production of mercury vapor during the combustion of fossil fuels (especially coals) represents a potentially important contribution because of the anticipated increase in coal-powered generating facilities. Several studies have indicated that, with the present technology for particulate capture, approximately 90 percent of the influent mercury from such facilities is lost to the atmosphere as mercury vapor. A wide variety of mercury concentrations is found in coal, depending on the geographical area and position within the deposit. The mercury concentration in coal varies from 0.012 to 450 ppm (Refs. 10, 51, 52, 54, 118, 119, 120, 129). Eastern coals are relatively higher than western coals in mercury content. The average concentration in the United States seems to be 0.2 ppm. In a study completed by the

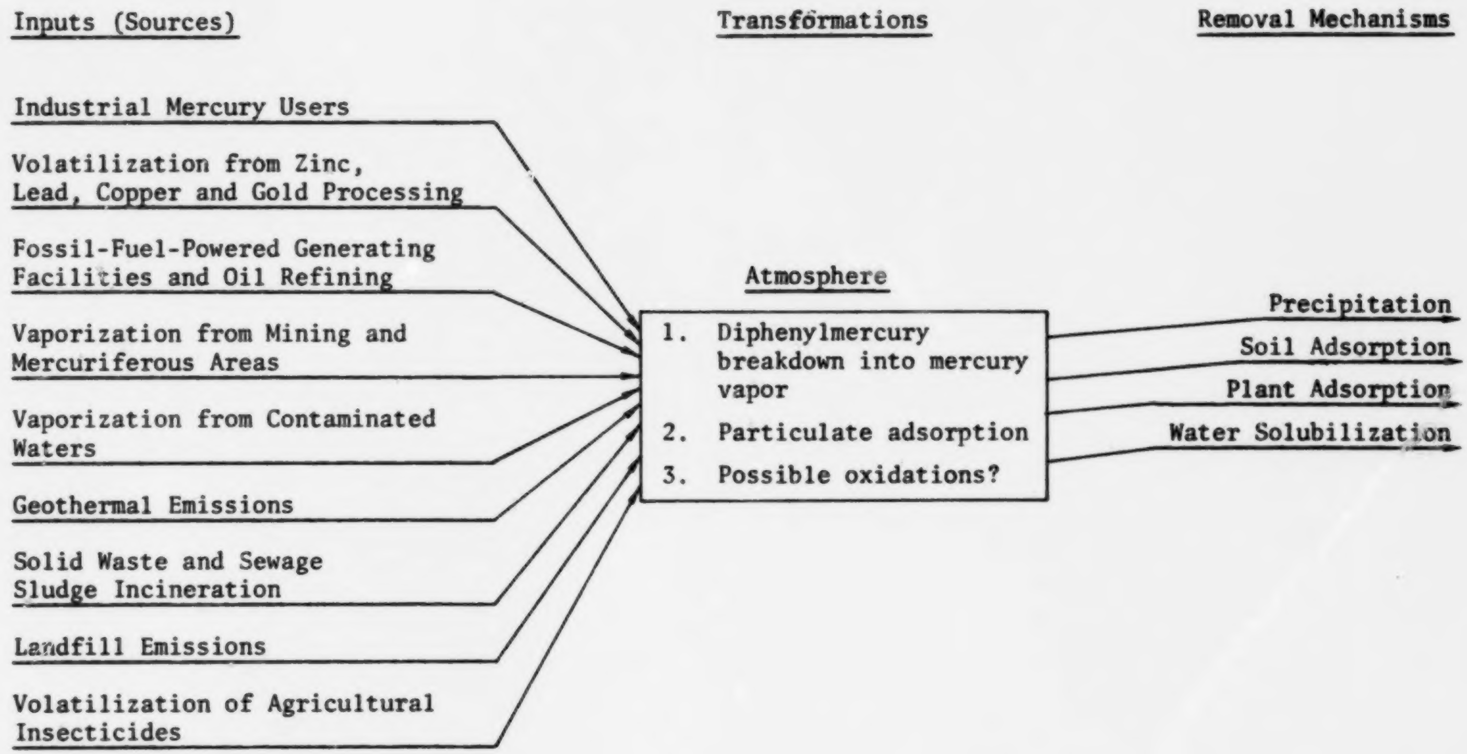
Inputs (Sources)
Transformations
Removal Mechanisms
Industrial Mercury Users
Volatilization from Zinc, Lead, Copper and Gold Processing
Fossil-Fuel-Powered Generating Facilities and Oil Refining
Vaporization from Mining and Mercuriferous Areas
Vaporization from Contaminated Waters
Geothermal Emissions
Solid Waste and Sewage Sludge Incineration
Landfill Emissions
Volatilization of Agricultural Insecticides
Atmosphere
1. Diphenylmercury breakdown into mercury vapor
2. Particulate adsorption
3. Possible oxidations?
Precipitation
Soil Adsorption
Plant Adsorption
Water Solubilization

FIGURE A-1. - Sources, Transformations, and Mechanisms for Removal of Mercury in the Atmosphere

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Source: URS Research Company

TABLE A-1. - Concentrations of Atmospheric Mercury Emissions

Source	Concentration	References
Coal-powered electrical generation	15-31 μg/m^3 in flue gas 0.012-150 ppm	10, 51, 52, 54, 118, 119, 120, 129
Nonferrous ore (zinc, copper, lead) processing	10 mg/m^3-80 ng/m^3 before control, 0.106-0.212 g/m^3 after	130
Geothermal emissions	10-28,000 ng/m^3	31
Natural degassing	10-1,600 ng/m^3 2,000-20,000 ng/m^3	34 132
Garbage incineration	Few to several thousand ng/m^3	131
Contaminated water bodies	400-4,000 ng/m^3 (downwind of chlor-alkali pond)	131
Background		
Urban	1-25 ng/m^3 winter, 2-50 ng/m^3 summer	133 133
Rural	1-10 ng/m^3	34, 132

Source: Compiled by URS Research Company

TVA, a scrubber system designed for sulfur dioxide removal was found to remove approximately 30 percent of the mercury from the collected fly ash and gas stream (Ref. 57).

The average concentration of mercury in U.S. crude oil is 0.05 ppm. Thus the combustion and refining of crude oil for electrical energy generation and gasoline production may also lead to significant mercury emissions. Mercury emission factors for the combustion of imported fuel vary from 0.000008 lb/10^3 gal to 0.001 lb/10^3 gal, and for U.S. crude oil the factors range from 0.00001 to 0.001 lb/10^3 gal. Most of the influent mercury probably reaches the atmosphere as mercury vapor (Ref. 2). One study that considered mercury in natural gas (Ref. 134) reported that the formation of insoluble compounds (chiefly sulfides) on pipeline walls reduced delivered gas mercury concentrations down to 1 to 2 ppb. Because of increased energy consumption, crude oil contributions will probably increase.

Considerable amounts of atmospheric mercury vapor result from the production of xzinc, lead, copper, and gold (Ref. 34). Where efforts have been made to recover ore-concentrated mercury, the outgoing processed gas still contained high levels -- 106 to 212 μg^3 of mercury (Ref. 130). Thus, the applicability of this process to waste gas streams containing 15 to 31 μg/m^3, as found in coal-powered generating plants, is open to question.

Mercury vapor also enters the atmosphere from mining and land development activities through natural degassing. Because metallic mercury has a very low vapor pressure, some mercury vapor is always being driven off. Decreases in barometric pressure and increases in temperature increase the rate of emission. Weiss (Ref. 8) has estimated that mercury released through natural degassing is 2-1/2 to 15 times that lost from industrial activities. Kothny (Ref. 24) has estimated natural degassing rates of 4.0 μg/m^2/day for Franciscan soils and 0.8 μg/m^2/day for normal soils. Using entirely different assumptions, Weiss developed an average world degassing rate of 1.5 μg/m^2/day. McCarthy (Ref. 18) showed that the degassing rate correlated better with mercury content of underlying mineral deposits than with the mercury concentration of the soil. He measured emission rates as low as 0.064 μg/m^2/day over unmineralized areas to as high as 41.9 μg/m^2/day over cinnabar veins.

Although insoluble mercuric sulfide is found in most natural deposits, chemical and biological processes produce mercury vapor. An example of a chemical process is the oxidation of sulfides to sulfates by ferric ions to free divalent mercuric ions, followed by the reduction of the mercuric ion to volatile elemental mercury and mercurous ion (Ref. 135). Bacteria are also able to oxidize mercuric sulfides, although the methylation rate of mercuric sulfide is 1,000 times slower than for mercuric chloride. Similar emissions could be expected from contaminated water bodies; measurements taken to date verify this supposition (Ref. 131).

Anticipated development of geothermal areas for power generation will increase local atmospheric levels of mercury, since likely areas for geothermal energy -- that is, zones of deep faulting and shearing -- are also zones of high mercury concentrations (Refs. 34, 132). Incinceration of sewage sludge and municipal refuse will contribute gaseous mercury vapor, as sewage sludge contains 4 to 8 ppm mercury and flue gas concentrations of several parts per million have been measured in a study of a New York City incinerator. As it appears that all of the mercury in sewage sludge and most of that in solid waste is volatilized, control devices able to capture more than particulate matter will be needed.

Other atmospheric emissions include those from chlor-alkali plants, agricultural fields sprayed with organomercurial insecticides, landfills containing mercury batteries and lamps, and walls covered with paints containing organomercurials.

Transformations and Fate

Although ambient concentrations are usually in the range of 1 to 10 ng/m^3, they vary greatly with the degree of mineralization and altitude, since the highest concentrations are found near the ground surface. Possible transformations involving airborne mercury are particulate adsorption and photodecomposition.

Means of atmospheric mercury removal include precipitation and plant, soil, and water adsorption and solubilization. Airborne concentrations of 20 μg/m^3 have been reduced to indetectable levels after precipitation (Ref. 132). Particulate adsorption of mercury compounds is frequently cited as the reason for the complete mercury removal achieved by rainfall. Other workers, however, have shown that considerable amounts of airborne mercury remain after precipitation; this finding results from their observation that most of the airborne mercury (more than 90 percent) is volatile and not particulate (Ref. 136).

Because of its volatile nature in air, once mercury is introduced into the atmosphere from a point source it tends to have a regional or global fate rather than a local one. That is, although the ambient air concentrations will be highest locally, local deposition is relatively minimal. Therefore point sources generally contribute more mercury to the total regional or global budget than to the local mercury budget. Most of this ends up in the oceans or the polar ice cap.

Environmental Effects

The effects of airborne toxicants depend upon (1) the amount and rate of adsorption and desorption, (2) the physiochemical and biological properties of the toxicant, and (3) individual susceptibility. No definitive human dose-response reactions have been observed, however. Therefore allowable environmental concentrations have been difficult to establish. The present EPA standard of 1 $\mu g/m^3$ of mercury vapor for 24-hour exposure is not based on inhalation studies, but was determined from knowledge of the total allowable human daily mercury intake and the average mercury consumption from food sources. The concentration of many emission sources clearly is greater than the EPA allowable standard. However, because of the distinct localization of the sources, most of the population inhales only background levels, which at an average of 10 ng/m^3 would only represent one-sixtieth of the allowable daily mercury consumption.

In summary, the air environment provides a convenient path for mercury and its compounds to cycle between land and water, and also acts as a dispersing and diluting medium for anomalous gaseous industrial and natural sources. The predominant mercury form may affect localized populations, but does not appear to affect populations exposed to background levels.

LAND ENVIRONMENT

Sources

Mercury enters the land environment in a variety of forms and from a variety of sources. Mercury sources, transformations, and outputs are shown in Figure A-2. Precipitation, deposition from industrial and natural degassing plumes, spraying and spreading of sewage effluents and sludges, filling of sanitary landfills, dredging of bottom sediments, and application of insecticides all add mercury to the environment.

Average reported rainfall concentrations are 0.2 ppb, although higher concentrations may occur in areas of abnormally high ambient mercury concentrations. In New Hampshire, an average value of 0.06 ppb was reported (Ref. 137); this is equivalent to a bulk precipitation rate of 0.23 $\mu g/m^2$/day. Mercury concentrations in landfills have ranged from 0.05 to 16.3 ppb. Average mercury concentrations of bottom sediments

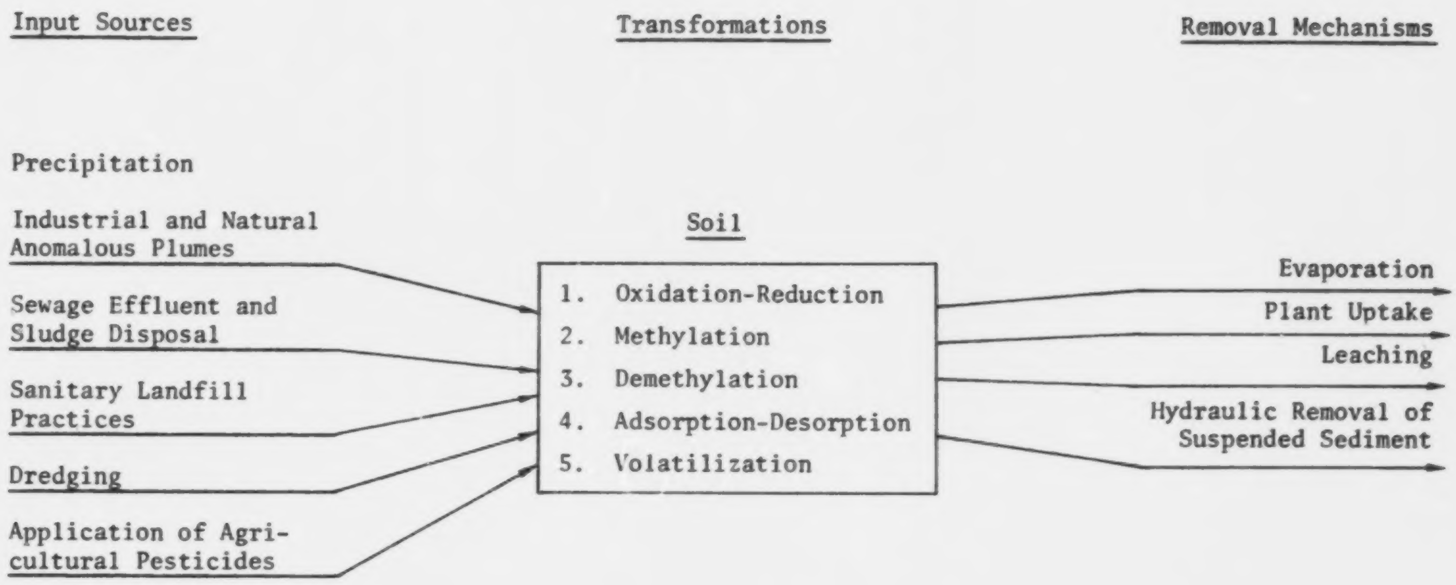
Input Sources
Transformations
Removal Mechanisms
Precipitation
Industrial and Natural Anomalous Plumes
Sewage Effluent and Sludge Disposal
Sanitary Landfill Practices
Dredging
Application of Agricultural Pesticides
Soil
1. Oxidation-Reduction
2. Methylation
3. Demethylation
4. Adsorption-Desorption
5. Volatilization
Evaporation
Plant Uptake
Leaching
Hydraulic Removal of Suspended Sediment

FIGURE A-2. - Sources, Transformations and Mechanisms for Removal of Mercury in the Land Environment

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Source: URS Research Company

range from 0.073 ppm to 0.3 ppm, depending on the nature of the body of water and proximity of industrial activity. Because organomercurial insecticide usage is generally restricted to croplands and golf courses, highest concentrations can be expected in such areas.

Transformations and Fate

Krenkel (Ref. 135) has stated that the average ambient soil mercury concentration is around 60 ppb, a value that depends on the degree of mineralization and the location of pollution sources. In some areas, soil concentrations can reach 150 to 200 ppb (with an extreme in Swedish soils of 922 ppb). The ultimate fate of this mercury will depend on the physiochemical, biological, and hydrological processes acting on the soil. These processes are not well understood, however, because soil is a complex and varying aggregation of inorganic gravel, silts, and clays and of organic humic and plant substances, which exhibit varying attractions for mercury compounds under different conditions. More understanding is being gained through modeling and through actual environmental measurements.

The physiochemical processes are adsorption, desorption, oxidation, reduction, and disproportionation. Because soil does contain complex constituents, mercury adsorption onto clays, sulfides, and humic water is promoted under mildly reducing conditions and lessened under others. Biological methylation may occur in heavily organic soils, leading to subsequent removal through volatilization under alkaline conditions. Plant uptake of mercury does not appear to be significant in terms of concentration or toxicity effects.

The average mercury concentrations in U.S. foods are quite low, ranging from 6 to 40 ppb, although they could be higher in crops grown in highly mineralized, polluted, or insect-infested areas (Ref. 2).

Mercury may also be removed from the soil environment through leaching and erosion of mercury-containing particulates. Leaching might be particularly important with regard to landfill operations and would depend upon the soil composition, chloride concentration, landfill design and operation, and oxidation-reduction potential. Measurements of leachate from landfills indicate that soil passage effectively attenuates mercury through adsorption, precipitations and exchange reactions. Because soil mercury is usually concentrated in the upper few centimeters of the soil column, erosion can transport a significant amount of mercury contamination to receiving waters.

Environmental Effects

Although few qualitative or quantitative data have been reported, it appears that the land environment offers a relatively permanent depot for mercury; the processes of metallic mercury volatization, plant uptake, leaching, and removal from surface layers by erosion serve to keep only a small portion of the land-applied mercury in the environmental cycle. Because mercury is not absorbed significantly by plants, its effects on the terrestial biological community are generally minimal.

WATER ENVIRONMENT

Mercury in the hydrosphere (and particularly in the freshwater environment) seems to offer the greatest threat to the human environment because of its continuous cycling within the water environment and the ability of aquatic organisms to concentrate mercury in their tissues. Figure A-3 shows the various sources, transformations, and removal mechanisms of mercury in the water environment.

Sources

Although chlor-alkali plants have contributed to significant localized mercury problems, improved housecleaning practices and efficient waste treatment processes will continue to decrease these plant emissions. The contribution of mercury-containing leachate is hard to quantify, but it has

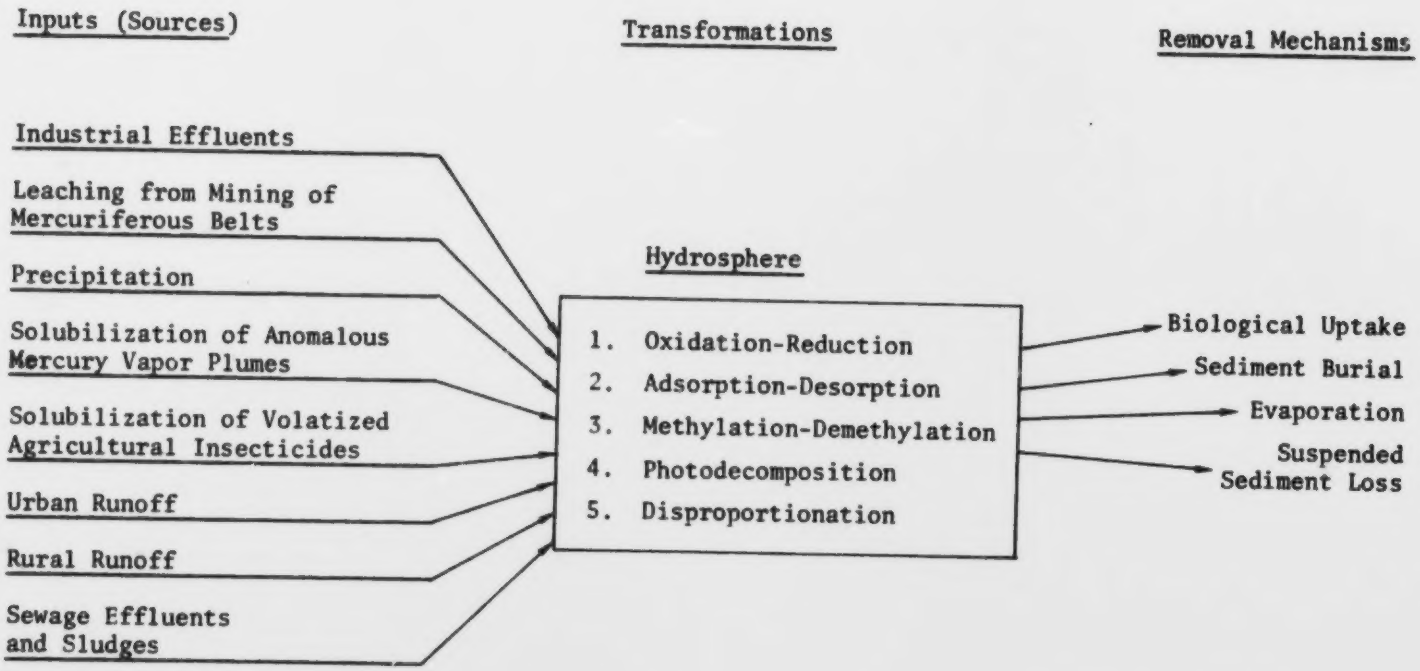
Inputs (Sources)
Transformations
Removal Mechanisms
Industrial Effluents
Leaching from Mining of Mercuriferous Belts
Precipitation
Solubilization of Anomalous Mercury Vapor Plumes
Solubilization of Volatized Agricultural Insecticides
Urban Runoff
Rural Runoff
Sewage Effluents and Sludges
Hydrosphere
1. Oxidation-Reduction
2. Adsorption-Desorption
3. Methylation-Demethylation
4. Photodecomposition
5. Disproportionation
Biological Uptake
Sediment Burial
Evaporation
Suspended Sediment Loss

FIGURE A-3. - Sources, Transformations and Mechanisms for Removal of Mercury in the Water Environment

Source: URS Research Company

been estimated that such processes amount to less than one-tenth the emissions from coal combustion. Precipitation may contain an average mercury concentration of 0.2 ppb. No information regarding the solubilization of inorganic and organic mercury-containing plumes from unregulated sources and foliar insecticide application was found, although one worker (Ref. 135) mentioned that high values found in Clear Lake, California, may be due to such a process. The contribution from urban runoff may be a significant localized source, and rural runoff contains mercury adsorbed onto suspended sediment. Sewage effluent and sludge may also be a significant localized source, in that higher ocean sediment mercury concentrations occur near ocean outfalls that discharge both sewage effluent and sludge. Sludge disposal is a particular problem, because of the ability of organic sludges to concentrate mercury and other heavy metals.

Transformations and Fate

As shown in Table A-2, typical ambient water column concentrations of mercury are low, and are well within the 2.0 ppb maximum allowable value set by the new EPA Drinking Water Standards. Although the transformation reactions occurring in water and sediment are similar to those occurring in soil, more information is available on water-sediment reactions, especially with regard to methylmercury and its compounds. The production of methylmercury in aquatic systems has been proven, and the factors determining its importance--that is, pH, oxidation-reduction (redox) potential, temperature, total mercury content, and microbiological community--have been elucidated (Ref. 138). Both mercuric ion and methylmercury are toxic to some bacterial species, which reduce both compounds to metallic vapor. Metallic vapor is less toxic than either compound because of its high volatility. This demethylation reaction acts to keep the concentration of sediment methylmercury relatively constant, which shows that the total mercury present and the methylmercury uptake by fish are better indicators of a contaminated sediment than is methylmercury concentration, which is about 1 percent of the total mercury value.

TABLE A-2. - Typical Ambient Concentrations of Mercury in the Hydrosphere

Characterization	(Concentration (ppb)		Reference
	Range	Average	
Streams, rivers, lakes	0.01 - 0.10[a]	0.03	6 7
Oceans and seas	0.03 - 5.0	0.2	6
Groundwaters	0.01 - 0.10	0.05	6
Hotsprings and mineral waters	0.01 - 2.5	0.10	6
Hot springs and mineral waters at Sonoma, California	0.7 - 0.13	0.10	19

a. Of 273 samples, 261 <1 ppb, 11 = 1 to 5 ppb, and 1 >5 ppb.

Source: Compiled by URS Research Company

The natural mechanisms for mercury removal are all well documented. Although dimethylmercury has a vapor pressure only a third to a half as great as that of metallic mercury, water bodies subjected to turbulent water and overlying air could transfer significant amounts of dimethylmercury and mercury vapor to the atmosphere. However, recent airborne mercury measurements over water bodies did not detect dimethylmercury (Ref. 136). Because sediment stabilization leads to decreased aquatic organism mercury uptake, mercury contained in buried, undisturbed sediments may have reached its ultimate fate. It is generally agreed that the half-life of mercury in such sediments varies from one to three years. In shallow, turbulent lakes, the removal of suspended sediment would tend to reduce mercury concentrations. The fourth removal mechanism, by aquatic life forms, has been clearly demonstrated. In one study, the ambient aqueous mercury concentration ranged from 0.05 to 0.13 ppm, while the algal mercury concentration ranged from 3,000 to 180,000 ppm.

The biological accumulation of methylmercury by fish is the most important aspect of the biological uptake system as far as man is concerned. Possible sources of the methylmercury may be the lower links of the food chain, methylmercury in the water column, or the innate ability of the organism to methylate inorganic and metallic mercury. The relative importance of the first two sources is still unquantified; the third does not appear to be important. Once in the fish, methylmercury is tightly retained with a half-life of from one to three years. No significant effects on fish containing normal amounts of methylmercury have been noticed, although extreme concentrations such as found in Minamata Bay fish led to anomalous behavior and metabolism.

D'Itri (Ref. 2) lists nine possible decontamination procedures for the removal or inactivation of mercury-containing sediments in aquatic ecosystems: (1) dredging or pumping, (2) conversion of all available mercury to mercuric sulfide, which is biologically unavailable for methylation; (3) evaporation of dimethylmercury into the atmosphere; (4) biological removal by bacteria; (5) burial under sand or other inorganic material;

(6) adsorption and burial with silicates or inert clays; (7) plastic coating applied to the bottom of mercury-contaminated lakes; (8) amalgamation with aluminum or other active metals; and (9) "biological mining" by clams. All methods are costly and only one -- dredging -- has been evaluated full-scale (Ref. 139). The results of that investigation indicate that high removal efficiencies are possible, although complete removal of all sediments must be accomplished for an appreciable effect on aqueous concentrations to occur.

Environmental Effects

Biological methylation and concentration are the important processes in the effects of mercury on humans. Different mercury compounds have different physiological effects, body retention times, and organ concentrations. Methylmercury and dimethylmercury are strongly held in brain tissue, whereas ingested mercuric ion tends to be concentrated in renal tissue and ingested metallic mercury has little effect at all. Because methylmercury is 5 to 20 times more toxic than other mercury forms, its concentration in food products, especially fish, is critically important.

The effect of methylmercury on aquatic organisms and predatory birds has been well documented (Ref. 135). The apparent difference between chemically and biologically synthesized mercury, however, needs further clarification. First, fish given chemically synthesized methylmercury are more sensitive to stress than those given biologically produced methylmercury; and second, fish accumulate 40 to 50 percent of chemically synthesized methylmercury versus 10 to 15 percent of biologically synthesized methylmercury.

In summary, the hydrosphere may be the ultimate fate for some mercury, a way station in the continuing atmospheric recycle for some, and the arena for biological methylation and concentration. However, the importance of methylmercury in sediments may not be as great as was once believed.

APPENDIX B

SELECTION OF STUDY REGIONS

Figure 1, presented in the Introduction to this report, is a map showing the selected study regions. This appendix describes the relevant characteristics of each region.

CALIFORNIA STUDY REGION

This study region extends from the San Francisco-Oakland metropolitan area through the Sierras and encompasses Reno (Nevada) and surrounding counties. It includes several metropolitan areas, relatively little heavy industry, considerable agricultural activity, and -- uniquely -- some of the major mercury-producing areas (and the only ones currently active in the nation). Considerable gold and silver are also found in this region, although mining activity has slowed in recent years.

ARIZONA STUDY REGION

All of Arizona, two desert counties in California, and the Las Vegas (Nevada) SMSA were selected for study, primarily because of the high ambient mercury air readings found throughout the region. These high readings were assumed to be associated with the several large copper smelters in Arizona. The region is relatively sparsely settled and has only two major metropolitan areas; heavy manufacturing is not a serious consideration.

LOUISIANA STUDY REGION

The southern half of Louisiana was included in this study region because it incorporates virtually all industrial activity in the state. This includes one of the most massive petrochemical complexes in the world as well as three large chlor-alkali plants.* The study region also included the Mississippi River, so that its role as a recipient of industrial and municipal wastes could be studied. (The Houston area, which is contiguous with the Gulf Coast of Louisiana, was initially considered for inclusion in the study region. However, its industrial composition was similar to that in Louisiana and its inclusion would have complicated the data analysis, so it was not included.)

KENTUCKY/TENNESSEE STUDY REGION

This region has a number of identified emitters, including two chlor-alkali plants, but of primary interest is the large number of unregulated emitters in the TVA power system. More than 20 large, coal-fired power plants were included, as were four metropolitan areas.

NEW YORK/NEW JERSEY STUDY REGION

The industrial complex of the State of New Jersey contains six or eight small manufacturers who account for almost 90 percent of the nation's mercury compound manufacturing. In addition, there are other chemical manufacturers and a number of refineries. The New York megalopolis, with its very high population density, has a number of coal-burning power plants and incinerates a large fraction of its solid wastes, including some sewage sludges. The study region also includes some electrical and control instrument manufacturers.

The five study regions not only have unique characteristics, but *in toto* they account for virtually every type of mercury emission of concern. In addition, they represent different socioeconomic concerns, climatic differences, and so on. Thus they provide a very diverse data base, which is at the same time all-inclusive for comparisons of regional variations and of regions with the national average.

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* When we speak of chlor-alkali plants, unless otherwise noted, we mean plants that use mercury cells.

UTILIZATION OF EXISTING MONITORING EMISSION DATA

In addition to the EPA map showing elevated mercury concentrations in the United States, the EPA also furnished an area ranking report for each EPA region which indicates average mercury emissions, in pounds per day, for each applicant under the RAPP permit program. These computer printout data were further "massaged" and, in most cases, obviously erroneous emissions were deleted; in some cases, locations which were not on the printouts were ascertained. However, attempts on the part of URS to verify reported emissions proved almost totally fruitless. In the California study region, for example, we went through each of the original applications to determine the applicant's estimate of likely mercury emissions and generally found that these were stated as "background" or slightly greater. In other regions obvious emitters, such as chlor-alkali plants, did not appear. (It has since been reported that the EPA considers that the files on these early permits are no longer useful.)

The Hazardous Air Polluting Emissions Monitoring System (HAPEMS), another computer printout that was obtained, reported air emissions for mercury mines and chlor-alkali plants. In general the data on these forms, which included location and a space for listing quantity of emission, could be verified. However, quantitative data usually were not given, and thus this program was of little use to us. (This program too has now been discontinued.)

Storage and Retrieval of Air Quality Data (SAROAD) were obtained to determine mercury concentrations in air. However, these data comprise only two points (both in Arizona) and were of little value. STORET printouts were obtained for each study region to aid in determining the average mercury content of surface waters and groundwaters. These data were generally useful, although the mercury contents displayed may be deceptively low because of the long standing time between sample collection and analysis and the infrequency of sample collection.

APPENDIX C

COMPUTER DATA BASE FORMAT AND USE

During this study a vast amount of information has been collected concerning mercury uses and losses. Because of the massive volume of this data, a data base management system was employed. The system used (called System 1022) is basically a device to turn raw data into useful information. The system permits making changes, updating, reordering, and analyzing the raw data. The software is owned by Tymshare, Inc., a world-wide computer time-sharing system, and is therefore proprietary.

FORMAT OF DATA BASE INPUT

The initial task in constructing any data base is to establish parameters or attributes that will be used in the final analysis. In the case of the mercury data base, 12 parameters have been chosen. A partial data coding form is shown in Table C-1. The titles above the actual data are the attribute names for each piece of data and are used when accessing that particular piece of information in the data base. Each line is a new set of information and corresponds to a single computer card or record.

- Columns 1-6 contain information pertaining to the SIC code. SIC stands for Standard Industrial Classification and is simply a means of categorizing the mercury emitters considered (see Section II). In this case, SIC 8021 stands for dental uses and SIC 49110 is power plants.

- Column 7 contains the sector within which the particular SIC falls. In the case of dental applications this is Sector VIII, and for power plants it is Sector III.

This allows extraction of mercury losses by economic sector, which one of the programs (to be described later) accomplishes.

TABLE C-1. - Data Coding Form

SIC	ICODE	NAME	LGD LGM	LD LM	STATE	CONTY	EINV	PROD	FPROD	EFA	EFW	EFL	ERE	CODE
8021	8	DENTAL	7349	4041	NY	QUEENS		631.0	HG	.04	.72		.24	K01A
8021	8	DENTAL	7356	4038	NY	KINGS		808.0	HG	.04	.72		.24	K02A
≈														≈
49110	3	PENNSGROVE	7528	3943	NY	SALEM		188.0	HG	.90		.10		F01A

*A standard card form, IBM electro [illegible], is available for punching statements from this form.

**Number of forms per pad may vary slightly

- Column 8-17 contain the name or location of the particular emitter or group of emitters. In this case, "dental" is simply the name of SIC category 8021, and Pennsgrove is the name of the power plant. When evaluating a copper smelter, for instance, these columns would contain the name of the particular smelter.

- Columns 18-20 and 21-22 are degrees and minutes, respectively, for the longitudinal coordinates of the mercury source. Columns 24-28 are the same for the latitudinal coordinates. These columns are used when specific emitters such as power plants, chlor-alkali plants, or mercurial chemical manufacturers can be rather precisely located. In a regional analysis, many SIC groups fall within an area source category, in which case the coordinates are the central point of a county. This is the situation in the case of dental losses, which cannot be defined by individual emitter. Columns 23 and 29 are not used.

- Columns 30-32 are used for a state abbreviation. Any abbreviation up to three characters can be used, as long as that use is consistent.

- Columns 33-39 give the county in which the mercury emissions occur. In the case of the national inventory the state names may go in these columns, which allows one of the FORTRAN programs to delineate mercury losses on a state-by-state basis.

- Columns 40-44 contain, if applicable, the amount of mercury a user may have on inventory.

- Columns 45-50 contain the total amount of mercury lost or recycled within a given county, state, or facility. For example, Queens County in the State of New York loses 631 pounds of mercury per year through dental usage, and the Pennsgrove power plant in Salem County, New York, emits 188 pounds per year. The totals in these columns could also represent the mercury lost during chlorine manufacture by a specific plant, or mercury lost in a given county from the disposal of batteries. In any case, the amount of mercury that is placed in these columns is that which is lost to air, land, or water or is recycled. The value represents the amount of raw mercury that is lost, although it may not be emitted in that form.

- Columns 51-54 are allocated for the form of mercury product emitted. Basically, this can be divided into three categories: organic (ORG), inorganic (INO), and metallic (HG).

- Columns 55-58, 59-62, 63-66, and 67-70 are the emission factors for mercury losses to air, water, land, and recycling, respectively. Adding across these four columns, the total should equal 1.0; i.e., 100 percent of the mercury available for loss is accounted for. These factors, therefore, can be multiplied by the value in columns 45-50 to obtain the amount of mercury lost to each parameter for the given SIC and geographical area (or mercury-using facility). In the case of the example for dental consumption, 4 percent of the mercury lost is vaporized to air, 72 percent is washed down the drain and therefore goes into water, 0 percent is lost to land, and 24 percent is recycled. In the burning of coal, 90 percent of the mercury is lost to air and 10 percent to land.

- Columns 71-75 are blank and can be used for adding other parameters, if necessary.

- Columns 76-80 are a numbered and lettered coding sequence to facilitate keeping the cards in order when reviewing the information contained on them.

LOADING THE DATA BASE FOR USE BY SYSTEM 1022

The keypunched data is loaded on a disk file and given the name URSHG.DMI. This data file is now ready to be loaded into System 1022; this is accomplished using the code shown below (assuming the user has logged into the Tymshare network). Note: The user must type the underlined characters:

```
     -LOAD URSHG.DMI
```

Several lines of information will be printed out, including how much storage is allocated for each parameter described above. This loading sequence is done in conjunction with a file called URSHG.DMD, which is a description of how the data appear on the cards and under what name each series of columns (discussed above) is referred to. For example, Columns 45-50, which contain the total amount of mercury lost to the environment (plus recycling) have a length of 6 columns and are referred to as PROD. A listing of this file is shown in Table C-2.

PURPOSE OF DATA BASE MANAGEMENT SYSTEM AND FEATURES OF THE OUTPUT

Once the data are successfully loaded into System 1022, the data base management system can be utilized to update or change the data with very simple commands. Running the FORTRAN source programs on the data base is a simple task. Assuming the programs are compiled and saved, only one command is necessary. The example below will be to run ALLSIC.

```
     -RUN ALLSIC
```

The program will then summarize mercury losses by SIC code to air, land, water, and recycling. The sample output for this and the remainder of the FORTRAN source programs follows this discussion.

To access System 1022, the user types the commands shown below:

```
     -    RUN (UPL) 1022
     -    OPEN URSHG
     *
```

TABLE C-2. - Listing of File URSHG.DMD

```
LOADING SECTION
INPUT URSHG.DMI
STRUCTURE SECTION
     ATTR SIC TEXT COL 1 6 KEYED
     ATTR ICODE TEXT LENGTH 1 KEYED
     ATTR NAME TEXT LENGTH 10 KEYED
     ATTR LGD INTEGER LENGTH 3 KEYED
     ATTR LGM INTEGER LENGTH 2 KEYED
     ATTR LGDR TEXT LENGTH I KEYED
     ATTR LD INTEGER LENGTH 3 KEYED
     ATTR LM INTEGER LENGTH 2 KEYED
     ATTR LDR TEXT LENGTH 1 KEYED
     ATTR STATE TEXT LENGTH 3 KEYED
     ATTR CONTY TEXT LENGTH 7 KEYED
     ATTR EFNV REAL LENGTH 5
     ATTR PROD REAL LENGTH 6
     ATTR FPROD TEXT LENGTH 4
     ATTR EFA REAL LENGTH 4
     ATTR EFW REAL LENGTH 4
     ATTR EFL REAL LENGTH 4
     ATTR ERE REAL LENGTH 4
     FILLER 12
```

The system responds with an asterisk, indicating that it is ready to accept another command. The following command must be to open the data base. The system responds with another asterisk and now it is ready to make any changes, additions, or deletions to the data base. It should be noted that these changes will <u>not</u> be made to the original data that were entered into the computer, but rather to the loaded data base, which is in a binary form.

To make a change in the binary data base, the user must first locate the particular record in question. This is done by a FIND command. For example, to change the emission factor to air for dental to 6 percent, the following sequence of commands would be used:

```
*    FIND SIC 8021
*    21 records
*    CHANGE EFA .06
*
```

All records for SIC 8021 would have the attribute EFA changed to .06.

Adding data is relatively simple, as the series of commands below will show. To add data, the system will interactively request the values for each attribute after the user has typed ADD.

```
*    ADD
     Supply other attributes
     SIC 8021
     ICODE 8
     NAME  DENTAL
     etc.
```

To delete, a FIND command is again necessary to locate the particular record (or records) to be deleted. Below, only one record, that for dental losses in Queens County, New York, is deleted.

```
*    FIND SIC 8021 CONTY QUEENS
     FOUND
*    DELETE
```

For any other specialized applications, the user should see the System 1022 Reference Manual. Leaving System 1022, the user simply types QUIT, and control is returned to the executive.

```
*    QUIT
```

The programs URSCTY, URSLL, MULFAC, and URSIC request specific inputs by the user. URSCTY requests a county and a sector; URSLL requests two points of longitude and two points of latitude; MULFAC requests an SIC code and a multiplying factor; and URSIC simply asks for an SIC. The output presented in the balance of this appendix illustrates the results of these programs.

SICALL - California Region

SIC Code	Total Losses to Land	Total Losses to Water	Total Losses to Air	Total Losses to Exports	Total Losses to Recycling
021	0.62	0.00	0.00	0.00	0.00
1021	0.00	0.00	0.01	0.00	0.00
1092M	0.07	0.01	0.02	0.00	0.00
1092P	0.44	0.00	8.34	0.00	0.00
2.5	0.69	0.14	0.05	0.00	0.00
2834C	0.00	1.18	0.00	0.00	0.00
2851C	1.87	0.93	12.14	0.00	0.00
2851M	0.00	0.02	0.02	0.00	0.00
2879	1.35	0.36	0.09	0.00	0.00
2911C	0.00	0.00	0.32	0.00	0.00
2951C	0.86	0.10	0.07	0.00	0.00
3.0	1.95	0.73	0.73	0.00	0.98
3241	0.14	0.02	0.02	0.00	0.00
3274	0.01	0.00	0.00	0.00	0.00
36292	5.32	0.00	0.00	0.00	0.00
36410	0.80	0.00	0.00	0.00	0.00
36420	27.02	0.00	1.15	0.00	1.60
38291	4.17	0.00	0.00	0.00	6.84
4091C	0.01	0.00	0.08	0.00	0.00
49110	0.00	0.00	0.29	0.00	0.00
4924C	0.00	0.00	1.25	0.00	0.00
4952	0.00	0.00	0.00	0.00	0.00
7391	0.80	0.53	0.53	0.00	0.00
8021	0.00	1.36	0.07	0.00	0.43
Total	46.11	5.38	25.19	0.00	9.84

SICALL - Arizona Region

SIC CODE	TOTAL LOSSES TO LAND	TOTAL LOSSES TO WATER	TOTAL LOSSES TO AIR	TOTAL LOSSES TO EXPORTS	TOTAL LOSSES TO RECYCLING
021	0.15	0.02	0.00	0.00	0.00
1021	0.07	0.00	0.10	0.00	0.00
2.5	0.21	0.04	0.01	0.00	0.00
2834C	0.00	0.40	0.09	0.00	0.00
2851C	0.24	0.00	4.63	0.00	0.00
2879	0.89	0.11	0.00	0.00	0.00
29C	0.80	0.30	1.50	0.00	0.00
3.0	0.63	0.24	0.24	0.00	0.32
3331	2.39	2.39	43.07	0.00	0.00
36292	2.29	0.00	0.00	0.00	0.00
36410	0.38	0.00	0.00	0.00	0.00
36420	8.20	0.00	2.11	0.00	0.50
38291	1.54	0.00	0.02	0.00	3.40
49110	0.00	0.00	0.05	0.00	0.00
7391	0.01	0.20	0.04	0.00	0.18
8021	1.05	0.84	0.02	0.00	0.12
	18.56	4.53	51.88	0.00	4.51

SICALL - Louisiana Region

SIC Code	Total Losses to Land	Total Losses to Water	Total Losses to Air	Total Losses to Exports	Total Losses to Recycling
021	0.00	0.07	0.01	0.00	0.00
2.5	0.65	0.12	0.04	0.00	0.00
2821	59.98	0.33	6.01	0.00	0.00
2834C	0.00	0.28	0.07	0.00	0.00
2851C	0.29	0.00	5.49	0.00	0.00
2879	1.34	0.17	0.00	0.00	0.00
2911C	0.00	0.00	0.29	0.00	0.00
2911M	0.28	0.00	0.28	9.76	0.00
2951C	0.44	0.05	0.02	0.00	0.00
3.0	0.61	0.23	0.23	0.00	0.27
36292	1.52	0.00	0.00	0.00	0.00
36410	0.38	0.00	0.00	0.00	0.00
36420	10.96	0.00	0.47	0.00	0.65
38291	0.96	0.00	0.01	0.00	2.27
49110	0.01	0.00	0.74	0.00	0.00
4924C	0.00	0.00	0.25	0.00	0.00
4924I	0.00	0.00	1.75	0.00	0.00
7391	0.26	0.19	0.05	0.00	0.00
8021	0.00	0.66	0.03	0.00	0.16
Total	77.69	2.10	15.74	9.76	3.35

SICALL - Tennessee Region

SIC Code	Total Losses to Land	Total Losses to Water	Total Losses to Air	Total Losses to Exports	Total Losses to Recycling
021	0.39	0.00	0.00	0.00	0.00
1099	0.00	0.00	0.01	0.00	0.00
2.5A	0.71	0.00	0.05	0.00	0.00
2.5B	0.10	0.38	0.00	0.00	0.00
2812	43.08	0.14	4.54	0.00	0.00
2834C	0.00	1.65	0.00	0.00	0.00
2851C	0.91	0.00	17.32	0.00	0.00
2851M	0.00	0.00	0.04	0.00	0.00
2879	3.14	0.53	0.00	0.00	0.00
2911C	0.00	0.00	0.57	0.00	0.00
2911M	0.03	0.00	0.03	0.00	0.00
2951C	2.13	0.24	0.16	0.00	0.00
3.0	2.02	0.76	0.76	0.00	1.01
3331	0.03	0.03	0.56	0.00	0.00
36292	9.65	0.00	0.00	0.00	0.00
36410	1.26	0.00	0.00	0.00	0.00
36420	30.31	0.00	1.30	0.00	1.80
38291	6.00	0.00	0.00	0.00	14.00
4091C	0.28	0.00	2.54	0.00	0.00
49110	1.75	0.00	15.81	0.00	0.00
4924C	0.00	0.00	0.93	0.00	0.00
7391	0.37	0.63	0.17	0.00	0.50
8021	0.00	1.84	0.07	0.00	0.45
9199	0.06	0.02	0.00	0.00	0.00
Total	102.21	6.23	44.87	0.00	17.76

URS

SICALL - New York/New Jersey

SUMMARY OF TOTAL LOSSES BY SIC CODE
(IN THOUSANDS OF LBS.)

SIC CODE	TOTAL LOSSES TO LAND	TOTAL LOSSES TO WATER	TOTAL LOSSES TO AIR	TOTAL LOSSES TO EXPORTS	TOTAL LOSSES TO RECYCLING
021	0.10	0.00	0.00	0.00	0.00
2.5A	1.60	0.00	0.39	0.00	0.00
2.5B	0.27	1.09	0.00	0.00	0.00
2812	23.92	0.30	4.49	0.00	25.02
2818M	0.04	0.64	0.04	0.00	0.00
2819M	0.00	0.09	0.00	0.00	0.00
2833M	0.00	0.03	0.00	0.00	0.00
2834C	0.5[illegible]	4.68	0.28	0.00	0.00
2851	2.54	0.00	48.31	0.00	0.00
2879	6.20	4.96	1.24	0.00	0.00
2911C	0.01	0.00	7.36	0.94	0.00
2911M	0.2[illegible]	0.00	0.2[illegible]	0.00	0.00
2951C	3.18	0.35	0.23	0.00	0.00
3.0	7.68	2.89	2.89	0.00	3.8[illegible]
3079P	0.12	0.40	0.02	0.00	0.00
3312M	0.06	0.00	0.31	0.00	0.00
36291C	12.69	0.00	2.78	0.00	0.00
36292M	2.56	0.00	0.13	0.00	0.00
36410C	10.04	0.00	2.24	0.00	0.00

SICALL - New York/New Jersey (cont.)

36410M	0.60	0.00	0.03	0.00	0.0[illegible]
36420C	102.71	0.0[illegible]	23.72	0.00	5.94
36420M	0.31	0.01	0.02	0.00	0.0[illegible]
38291C	27.16	0.0[illegible]	0.0[illegible]	0.0[illegible]	32.4[illegible]
38291M	1.2	0.0[illegible]	0.0[illegible]	0.0[illegible]	0.0[illegible]
4091C	0.37	[illegible].0[illegible]	3.[illegible]	0.0[illegible]	0.0[illegible]
4911C	0.51	0.0[illegible]	9.80	0.0[illegible]	0.[illegible]
4924C	0.[illegible]	0.01	1.76	0.0[illegible]	0.[illegible]
7391	0.4[illegible]	1.64	0.63	0.[illegible]	3.59
8021	0.[illegible]	0.0[illegible]	0.24	0.0[illegible]	1.45
	205.67	[illegible].07	1[illegible]0.57	0.94	72.[illegible]8

SICALL - National

SUMMARY OF TOTAL LOSSES BY SIC CODE
(IN THOUSANDS OF LBS.)

SIC CODE	TOTAL LOSSES TO LAND	TOTAL LOSSES TO WATER	TOTAL LOSSES TO AIR	TOTAL LOSSES TO EXPORTS	TOTAL LOSSES TO RECYCLING
021	39.02	0.00	0.00	0.00	0.00
1021	0.17	0.02	0.05	0.00	0.00
1031	0.03	0.00	0.01	0.00	0.00
1092M	0.03	0.00	0.01	0.00	0.00
1092P	0.91	0.00	17.29	0.00	0.00
2.5A	4.89	0.00	0.26	0.00	0.00
2.5B	4.20	16.79	0.00	0.00	0.00
2.61	16.83	0.34	0.00	0.00	0.00
2812	506.17	6.46	32.73	0.00	0.00
2819M	0.00	0.05	0.00	0.00	0.00
283 M	0.00	0.04	0.00	0.00	0.00
2834C	4.61	39.18	2.30	0.00	0.00
2851C	20.15	0.00	382.80	0.00	0.00
2851F	0.00	0.7[illegible]	0.63	0.00	0.00
2851M	0.10	0.45	0.03	0.00	0.00
2879C	48.39	38.72	9.68	0.00	0.00
2879F	35.33	6.23	0.00	0.00	0.00
2879M	0.01	0.13	0.01	0.00	0.00

URS

SICALL - National (cont.)

2911C	0.04	0.00	37.35	0.00	0.00
2911M	2.54	0.00	2.54	0.00	0.00
2951C	33.06	3.68	2.43	0.00	0.00
3.0	60.74	22.78	22.78	0.00	45.55
3079P	0.00	0.01	0.00	0.00	0.00
3241	3.88	0.55	1.11	0.00	0.00
3274	0.64	0.09	0.18	0.00	0.00
3312M	5.64	1.13	15.79	0.00	0.00
3[illegible]1	4.99	4.99	89.89	0.00	0.00
3[illegible]2	0.58	0.58	10.48	0.00	0.00
3[illegible]	0.56	0.56	10.1	0.00	0.00
36292C	102.00	0.00	16.00	0.00	0.00
36292M	3.47	0.00	0.00	0.00	0.00
36410C	82.26	0.00	13.39	0.00	0.00
36410M	2.98	0.00	0.84	0.00	0.00
36420C	8[illegible]9.27	0.00	153.70	0.00	54.89
36420M	5.48	0.12	0.29	0.00	0.00
38291C	237.03	0.00	36.47	0.00	182.3[illegible]
38291M	4.34	0.00	0.00	0.00	0.00
4091C	2.4[illegible]	0.00	21.98	0.00	0.00
491[illegible]0	0.03	0.00	20.43	0.00	0.00
4911C	9.97	0.00	84.7[illegible]	0.00	0.00
4924C	0.03	0.00	34.09	0.00	0.00
7391	3.51	13.05	5.02	0.00	28.62
8021	0.00	36.72	2.04	0.00	12.24
	2130.32	193.47	1039.08	0.00	323.64

CTYALL - California Region

County	Total Losses to Land	Total Losses to Water	Total Losses to Air	Total Losses to Exports	Total Losses to Recycling
Alameda	7.96	0.96	2.78	0.00	1.90
Alpine	0.00	0.00	0.00	0.00	0.00
Amador	0.08	0.01	0.03	0.00	0.00
Calaveras	0.11	0.01	0.04	0.00	0.00
Church	0.08	0.01	0.03	0.00	0.00
Contra Costa	3.66	0.45	1.64	0.00	0.72
Douglas	0.05	0.00	0.02	0.00	0.00
Eldorado	0.25	0.03	0.11	0.00	0.01
Lyon	0.06	0.01	0.03	0.00	0.00
Marin	1.22	0.15	1.64	0.00	0.06
Merced	0.71	0.07	0.25	0.00	0.03
Napa	0.60	0.06	1.79	0.00	0.03
Placer	0.46	0.05	0.20	0.00	0.03
Sacramento	3.69	0.44	1.56	0.00	0.60
Santa Clara	9.99	1.19	6.51	0.00	2.61
Santa Cruz	0.92	0.11	0.46	0.00	0.20
San Francisco	5.08	0.55	1.77	0.00	1.46
San Joaquin	1.97	0.21	0.71	0.00	0.40
San Mateo	3.88	0.48	1.41	0.00	0.95
Solano	0.98	0.12	0.45	0.00	0.21
Sonoma	1.42	0.16	2.69	0.00	0.07
Stanislaus	1.47	0.15	0.49	0.00	0.30
Storey	0.00	0.00	0.00	0.00	0.00
Tuolumne	0.15	0.02	0.05	0.00	0.01
Washoe	0.77	0.10	0.33	0.00	0.20
Yolo	0.55	0.06	0.20	0.00	0.03
Total	46.11	5.38	25.19	0.00	9.84

CTYALL - Arizona Region

SUMMARY OF TOTAL LOSSES BY COUNTY
(IN THOUSANDS OF LBS.)

COUNTY	TOTAL LOSSES TO LAND	TOTAL LOSSES TO WATER	TOTAL LOSSES TO AIR	TOTAL LOSSES TO EXPORTS	TOTAL LOSSES TO RECYCLING
CU[illegible]	0.[illegible]	0.	0.[illegible]	0.[illegible]	0.[illegible]
CLARK	2.05	0.20	1.34	0.[illegible]	0.32
COCHISE	0.32	0.32	5.70	0.[illegible]	0.[illegible]
CO[illegible]	0.41	0.[illegible]5	0.26	0.[illegible]	0.[illegible]6
GILA	1.[illegible]	1.00	18.[illegible]1	0.[illegible]	0.[illegible]7
GRE[illegible]NL	0.47	0.40	0.5	0.[illegible]	0.[illegible]
[illegible]	1.[illegible]1	0.[illegible]5	0.10	0.[illegible]	0.[illegible]0
MARICOP	[illegible]	1.[illegible]	4.70	0.[illegible]	3.02
[illegible]	0.10	[illegible]	0.13	0.[illegible]	0.[illegible]3
PIMA	5.01	0.[illegible]	3.72	0.[illegible]	0.[illegible]8
PINAL	0.90	0.[illegible]	7.98	0.[illegible]	0.1[illegible]
[illegible]	[illegible].[illegible]0	[illegible].[illegible]1	0.[illegible]3	0.[illegible]	0.[illegible]
SANC[illegible]RZ	[illegible].1[illegible]	0.[illegible]1	0.[illegible]7	0.[illegible]	0.[illegible]2
YAV	0.29	0.[illegible]4	0.2[illegible]	0.[illegible]	0.[illegible]5
YUMA	0.40	0.[illegible]	0.32	0.[illegible]	0.[illegible]0
	18.56	4.[illegible]7	[illegible]1.8	0.[illegible]	4.51

CTYALL - Tennessee Region

COUNTY	TOTAL LOSSES TO LAND	TOTAL LOSSES TO WATER	TOTAL LOSSES TO AIR	TOTAL LOSSES TO EXPORTS	TOTAL LOSSES TO RECYCLING
KEN01	0.78	0.07	1.55	0.00	0.17
KEN02	27.27	0.17	3.15	0.00	0.25
KEN03	0.61	0.07	0.43	0.00	0.14
KEN04	0.71	0.07	0.75	0.00	0.16
KEN05	0.78	0.08	0.36	0.00	0.25
KEN06	0.96	0.08	2.02	0.00	0.23
KEN07	0.84	0.08	0.74	0.00	0.25
KEN08	0.76	0.08	0.31	0.00	0.22
KEN09	0.87	0.08	1.05	0.00	0.22
KEN10	0.57	0.07	0.30	0.00	0.11
KEN11	0.54	0.07	0.22	0.00	0.07
KEN12	0.62	0.07	0.92	0.00	0.07
KEN13	0.63	0.07	0.25	0.00	0.13
KEN14	0.80	0.07	2.31	0.00	0.09
KEN15	0.79	0.10	0.42	0.00	0.18
KEN16	0.74	0.07	0.28	0.00	0.23
KEN17	6.09	0.61	4.57	0.00	2.00
KEN18	0.89	0.07	2.04	0.00	0.21
KEN19	0.75	0.08	0.34	0.00	0.21
KEN20	0.73	0.08	0.72	0.00	0.19
KEN21	1.27	0.15	0.70	0.00	0.32
KEN22	0.76	0.08	0.33	0.00	0.20
KEN23	0.78	0.08	0.33	0.00	0.23
KEN24	1.50	0.10	0.34	0.00	0.78
KEN25	0.68	0.07	0.30	0.00	0.21
KEN26	0.96	0.10	0.44	0.00	0.29
TEN01	0.89	0.09	0.36	0.00	0.31
TEN02	0.61	0.06	0.24	0.00	0.18
TEN03	0.73	0.07	0.28	0.00	0.24
TEN04	0.75	0.08	0.28	0.00	0.24
TEN05	0.92	0.09	0.35	0.00	0.36
TEN06	0.89	0.09	1.11	0.00	0.31
TEN07	0.82	0.08	0.30	0.00	0.31
TEN08	0.63	0.06	0.24	0.00	0.19
TEN09	3.38	0.38	1.56	0.00	0.97
TEN10	0.94	0.09	1.05	0.00	0.29

CTYALL - Tennessee Region (cont.)

COUNTY	TOTAL LOSSES TO LAND	TOTAL LOSSES TO WATER	TOTAL LOSSES TO AIR	TOTAL LOSSES TO EXPORTS	TOTAL LOSSES TO RECYCLING
TEN11	0.74	0.09	0.22	0.00	0.26
TEN12	0.90	0.07	0.38	0.00	0.31
TEN13	0.81	0.09	0.32	0.00	0.27
TEN14	0.80	0.08	0.34	0.00	0.26
TEN15	0.84	0.08	0.30	0.00	0.27
TEN16	0.56	0.06	0.23	0.00	0.19
TEN17	0.93	0.09	1.02	0.00	0.27
TEN18	2.17	0.27	1.00	0.00	0.59
TEN19	0.84	0.08	0.31	0.00	0.30
TEN20	1.02	0.09	1.44	0.00	0.34
TEN21	17.69	0.18	2.67	0.00	0.39
TEN22	0.55	0.06	0.22	0.00	0.19
TEN23	1.23	0.12	0.91	0.00	0.41
TEN24	1.17	0.11	0.47	0.00	0.45
TEN25	0.76	0.08	0.30	0.00	0.45
TEN26	0.54	0.05	0.18	0.00	0.24
TEN27	5.27	0.61	2.71	0.00	1.39
TEN28	2.18	0.23	0.94	0.00	0.74
	102.88	6.26	45.43	0.00	17.76

CTYALL - New York/New Jersey

SUMMARY OF TOTAL LOSSES BY COUNTY
(IN THOUSANDS OF LBS.)

COUNTY	TOTAL LOSSES TO LAND	TOTAL LOSSES TO WATER	TOTAL LOSSES TO AIR	TOTAL LOSSES TO EXPORTS	TOTAL LOSSES TO RECYCLING
BERGEN	8.03	1.11	2.88	0.07	1.61
BRONX	11.83	1.18	3.59	0.05	1.81
BUCKS	3.02	0.40	2.01	0.[illegible]	1.46
BURLING	2.72	0.28	0.92	0.02	0.48
CAMDEN	4.05	0.41	1.58	0.03	0.76
DELAWAR	4.04	0.53	3.79	0.06	1.76
ESSEX	8.36	0.95	2.94	0.07	1.62
FAIRFIE	5.08	0.75	4.34	0.01	2.78
GLOUCES	1.5[illegible]	0.16	0.57	0.01	0.30
HARTFOR	5.36	0.76	3.98	0.01	2.80
HUDSON	5.67	0.73	1.95	0.04	1.17
HUNTER	0.79	0.20	0.95	0.01	0.12
KINGS	14.76	2.1[illegible]	11.9[illegible]	0.09	3.46
LITCHFI	0.96	0.13	0.68	0.[illegible]	0.5[illegible]
MERCER	2.80	0.29	1.02	0.02	0.51
MIDDLES	5.60	0.56	2.55	0.04	1.21
MONMOUT	3.72	0.39	1.24	0.03	0.60
MONTGOM	4.50	0.58	3.37	0.06	2.11
MORRIS	3.49	0.40	1.25	0.03	0.70
NASSAU	9.74	1.2[illegible]	7.12	0.05	1.89

CTYALL - New York/New Jersey (cont.)

NEWCAST	3.50	0.37	1.17	0.03	0.64
NEWHAVE	5.31	0.70	3.43	0.01	2.60
NEWYORK	8.81	1.33	8.94	0.05	2.09
OCEAN	0.00	0.04	0.00	0.00	0.00
PASSAIC	4.07	0.76	1.56	0.03	0.99
PHILADE	16.87	1.71	8.79	0.06	5.38
QUEENS	12.00	1.76	11.11	0.07	2.91
RICHMON	0.02	0.00	0.21	0.00	0.00
ROCKLAN	1.76	0.20	0.91	0.01	0.31
SALEM	0.69	0.07	0.40	0.00	0.14
SOMERSE	1.82	0.23	0.66	0.01	0.39
SUFFOLK	7.75	0.95	4.21	0.04	1.43
TOLLAND	0.69	0.10	0.48	0.00	0.35
UNION	29.08	0.91	6.37	0.04	26.13
WARREN	0.00	0.01	0.00	0.00	0.00
WESTCHE	6.23	0.78	3.72	0.03	1.24
	205.07	23.07	110.57	0.94	72.26

CTYALL - National

SUMMARY OF TOTAL LOSSES BY COUNTY
(IN THOUSANDS OF LBS.)

COUNTY	TOTAL LOSSES TO LAND	TOTAL LOSSES TO WATER	TOTAL LOSSES TO AIR	TOTAL LOSSES TO EXPORTS	TOTAL LOSSES TO RECYCLING
ALABAMA	90.44	3.44	21.80	0.00	5.43
ARIZONA	15.17	3.89	49.12	0.00	2.11
ARKANSA	15.64	1.58	6.71	0.00	2.91
CALIFOR	143.80	16.69	81.03	0.00	28.6
COLORAD	17.10	2.07	7.73	0.00	2.57
CONNECT	25.85	2.84	13.3	0.00	6.28
DCOLUMB	0.06	0.11	0.52	0.00	0.06
DELAWAR	23.32	0.77	4.25	0.00	0.97
FLORIDA	45.41	5.31	26.61	0.00	7.68
GEORGIA	62.11	4.24	21.02	0.00	7.63
IDAHO	5.80	0.8	6.13	0.00	1.06
ILLINOI	104.96	10.06	49.48	0.05	20.31
INDIANA	46.56	5.01	26.83	0.00	10.57
IOWA	23.97	2.30	12.46	0.00	3.91
KANSAS	24.31	3.12	8.07	0.00	2.76
KENTUCK	64.94	2.97	23.17	0.00	4.67
LOUISIA	101.7	3.38	18.47	0.00	3.89
MAINE	16.23	0.9	5.61	0.00	1.80
MARYLAN	29.2	3.46	16.67	0.00	5.82
MASSACH	46.15	5.11	25.06	0.00	10.38
MICHIGA	72.84	8.21	41.51	0.00	17.13
MINNESO	30.74	3.54	15.47	0.00	5.53

CTYALL - National (cont.)

MISSISS	16.74	1.80	11.26	0.00	3.12
MISSOUR	38.02	4.45	30.39	0.00	7.26
MONTANA	9.19	1.63	8.75	0.00	0.61
NEBRASK	13.55	1.56	5.10	0.00	1.72
NEVADA	4.17	0.71	12.44	0.00	0.44
NEWHAMP	6.48	0.70	3.17	0.00	1.48
NEWJERS	92.40	7.42	32.13	0.00	13.63
NEWMEXI	6.56	1.12	10.73	0.00	0.81
NEWYORK	172.97	15.74	78.2[illegible]	0.00	28.75
NORTHCA	55.74	4.79	26.97	0.00	10.25
NORTHDA	14.09	2.14	2.0[illegible]	0.00	0.42
OHIO	95.87	9.89	55.86	0.00	20.97
OKLAHOM	23.16	2.79	10.07	0.00	3.04
OREGON	15.73	1.79	7.97	0.00	2.94
PENNSYL	101.92	11.29	76.80	0.00	22.65
RHODEIS	8.69	0.90	4.02	0.00	1.98
SOUTHCA	28.62	2.53	12.1	0.00	5.01
SOUTHDA	7.58	0.93	2.4[illegible]	0.00	0.59
TENNESS	69.84	5.0[illegible]	2[illegible].04	0.00	7.02
TEXAS	131.05	10.36	57.08	0.00	14.73
UTAH	7.99	1.59	17.28	0.00	1.25
VERMONT	3.19	0.34	1.53	0.00	0.65
VIRGINI	3[illegible].81	3.8[illegible]	17.94	0.00	6.72
WASHING	49.45	3.31	19.80	0.00	4.70
WISCONS	45.6[illegible]	5.10	18.49	0.00	8.11
WVIRGIN	68.[illegible]5	1.7	11.81	0.00	2.27
WYOMING	2.60	0.25	1.64	0.00	0.28
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	2130.32	193.47	1039.08	0.00	323.64

URSIC New York/New Jersey - SIC 36420C: Battery Consumption

SUMMARY OF LOSSES

		TOTAL	<5 LBS	5-25 LBS	26-100 LBS	101-400 LBS	>400 LBS
LOSSES	NO.	31	0	2	6	10	13
TO AIR	LBS.	23720.71	0.00	30.87	[illegible]	[illegible]	21742.75
LOSSES	NO.	[illegible]	0	0	0	3	30
TO LAND	LBS.	[illegible]	0.00	0.00	0.00	1004.57	[illegible]
LOSSES	NO.	0	0	0	0	0	0
TO WATER	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES	NO.	0	0	0	0	0	0
TO EXPT	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES	NO.	[illegible]	0	3	8	19	[illegible]
TO RECY	LBS.	5937.40	0.00	59.37	554.37	[illegible]	[illegible]

URSIC New York/New Jersey - SIC 3079 P: Vat Dyes

SUMMARY OF LOSSES

		TOTAL	<5 LBS	5-25 LBS	26-100 LBS	101-400 LBS	>400 LBS
LOSSES	NO.	10	10	0	0	0	0
TO AIR	LBS.	22.16	22.16	0.00	0.00	0.00	0.00
LOSSES	NO.	10	10	0	0	0	0
TO LAND	LBS.	22.16	22.16	0.00	0.00	0.00	0.00
LOSSES	NO.	10	0	2	8	0	0
TO WATER	LBS.	398.93	0.00	39.87	359.06	0.00	0.00
LOSSES	NO.	0	0	0	0	0	0
TO EXPT	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES	NO.	0	0	0	0	0	0
TO RECY	LBS.	0.00	0.00	0.00	0.00	0.00	0.00

URSIC New York/New Jersey - SIC 2833 M: Pharmaceutical Manufacture

SUMMARY OF LOSSES

		TOTAL	<5 LBS	5-25 LBS	26-100 LBS	101-400 LBS	>400 LBS
LOSSES TO AIR	NO.	2	2	0	0	0	0
	LBS.	1.58	1.58	0.00	0.00	0.00	0.00
LOSSES TO LAND	NO.	2	2	0	0	0	0
	LBS.	1.58	1.58	0.00	0.00	0.00	0.00
LOSSES TO WATER	NO.	2	0	2	0	0	0
	LBS.	28.51	0.00	28.51	0.00	0.00	0.00
LOSSES TO EXPT	NO.	0	0	0	0	0	0
	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES TO RECY EXIT	NO.	0	0	0	0	0	0
	LBS.	0.00	0.00	0.00	0.00	0.00	0.00

URSIC New York/New Jersey - SIC 2819 M: Catalyst Manufacture

SUMMARY OF LOSSES

		TOTAL	<5 LBS	5-25 LBS	26-100 LBS	101-400 LBS	>400 LBS
LOSSES TO AIR	NO.	7	7	0	0	0	0
	LBS.	4.74	4.74	0.00	0.00	0.00	0.00
LOSSES TO LAND	NO.	7	7	0	0	0	0
	LBS.	4.74	4.74	0.00	0.00	0.00	0.00
LOSSES TO WATER	NO.	7	2	4	1	0	0
	LBS.	85.3[illegible]	9.48	48.37	27.49	0.00	0.00
LOSSES TO EXPT	NO.	0	0	0	0	0	0
	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES TO RECY	NO.	0	0	0	0	0	0
	LBS.	0.00	0.0	0.00	0.00	0.00	0.00

URSIC New York/New Jersey - SIC 2818 M:

SUMMARY OF LOSSES

		TOTAL	<5 LBS	5-25 LBS	26-100 LBS	101-400 LBS	>400 LBS
LOSSES TO AIR	NO.	7	4	3	0	0	0
	LBS.	35.63	9.67	25.96	0.00	0.00	0.00
LOSSES TO LAND	NO.	7	4	3	0	0	0
	LBS.	35.63	9.67	25.96	0.00	0.00	0.00
LOSSES TO WATER	NO.	7	0	1	3	3	0
	LBS.	641.26	0.00	14.15	159.87	467.24	0.00
LOSSES TO EXPT	NO.	0	0	0	0	0	0
	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES TO RECY	NO.	0	0	0	0	0	0
	LBS.	0.00	0.00	0.00	0.00	0.00	0.00

URSIC New York/New Jersey - SIC 7391 : Laboratory

SUMMARY OF LOSSES

		TOTAL	<5 LBS	5-25 LBS	26-100 LBS	101-400 LBS	>400 LBS
LOSSES TO AIR	NO.	33	5	21	7	0	0
	LBS.	629.00	15.00	313.50	301.50	0.00	0.00
LOSSES TO LAND	NO.	33	7	21	5	0	0
	LBS.	440.30	18.20	253.05	169.05	0.00	0.00
LOSSES TO WATER	NO.	33	0	9	20	4	0
	LBS.	1635.40	0.00	116.50	991.90	53[illegible].00	0.00
LOSSES TO EXPT	NO.	0	0	0	0	0	0
	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES TO RECY	NO.	33	0	4	16	13	0
	LBS.	3585.30	0.00	59.85	1026.00	2499.45	0.00

URSIC New York/New Jersey - SIC 36420M: Battery Manufacture

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SUMMARY OF LOSSES
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                       TOTAL        <5        5-25      26-100    101-400      >400
                                    LBS        LBS         LBS        LBS       LBS

LOSSES    NO.            1           0          1          0          0          0
TO AIR    LBS.       16.64        0.00      16.64       0.00       0.00       0.00

LOSSES    NO.            1           0          0          0          1          0
TO LAND   LBS.      309.54        0.00       0.00       0.00     309.54       0.00

LOSSES    NO.            1           0          1          0          0          0
TO WATER  LBS.        0.00        0.00       0.00       0.00       0.00       0.00

LOSSES    NO.            0           0          0          0          0          0
TO EXPT   LBS.        0.00        0.00       0.00       0.00       0.00       0.00

LOSSES    NO.            0           0          0          0          0          0
TO RECY   LBS.        0.          0.00       0.00       0.00       0.00       0.00
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URSIC New York/New Jersey - SIC 2834 C: Pharmaceutical Consumption

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SUMMARY OF LOSSES
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                       TOTAL        <5        5-25      26-100    101-400      >400
                                    LBS        LBS         LBS        LBS       LBS

LOSSES    NO.           33          12         20          1          0          0
TO AIR    LBS.      275.25       32.55     213.80      28.90       0.00       0.00

LOSSES    NO.           33           6         20          7          0          0
TO LAND   LBS.      550.50       17.20     262.60     270.70       0.00       0.00

LOSSES    NO.            3           0          3         12         17          1
TO WATER  LBS.     4679.25        0.00      47.60     782.00    3358.35     491.30

LOSSES    NO.            0           0          0          0          0          0
TO EXPT   LBS.        0.00        0.00       0.00       0.00       0.00       0.00

LOSSES    NO.            0           0          0          0          0          0
TO RECY   LBS.        0.00        0.00       0.00       0.00       0.00       0.00
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URSIC New York/New Jersey - SIC 2879 : Pesticides

SUMMARY OF LOSSES

		TOTAL	<5 LBS	5-25 LBS	26-100 LBS	101-400 LBS	>400 LBS
LOSSES TO AIR	NO.	3	1	12	18	2	0
	LBS.	1240.70	4.20	181.00	840.70	214.80	0.00
LOSSES TO LAND	NO.	3	0	1	4	20	2
	LBS.	6203.50	0.00	21.00	582.50	4040.00	1560.00
LOSSES TO WATER	NO.	3	0	1	12	18	2
	LBS.	4962.80	0.00	16.80	724.00	3362.80	859.20
LOSSES TO EXPT	NO.	0	0	0	0	0	0
	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES TO RECY	NO.	0	0	0	0	0	0
	LBS.	0.00	0.00	0.00	0.00	0.00	0.00

URSIC New York/New Jersey - SIC 021 : Livestock

SUMMARY OF LOSSES

		TOTAL	<5 LBS	5-25 LBS	26-100 LBS	101-400 LBS	>400 LBS
LOSSES TO AIR	NO.	0	0	0	0	0	0
	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES TO LAND	NO.	25	16	9	0	0	0
	LBS.	96.40	27.20	69.20	0.00	0.00	0.00
LOSSES TO WATER	NO.	0	0	0	0	0	0
	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES TO EXPT	NO.	0	0	0	0	0	0
	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES TO RECY	NO.	0	0	0	0	0	0
	LBS.	0.00	0.00	0.00	0.00	0.00	0.00

URSIC New York/New Jersey - SIC 49110 : Utilities - Oil and Gas

SUMMARY OF LOSSES

		TOTAL	<5 LBS	5-25 LBS	26-100 LBS	101-400 LBS	>400 LBS
LOSSES	NO.	52	17	9	9	10	7
TO AIR	LBS.	9795.56	36.57	100.04	466.50	1898.98	7355.42
LOSSES	NO.	52	44	4	2	2	0
TO LAND	LBS.	512.4	16.64	83.10	125.80	266.90	0.00
LOSSES	NO.	0	0	0	0	0	0
TO WATER	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES	NO.	0	0	0	0	0	0
TO EXPT	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES	NO.	0	0	0	0	0	0
TO RECY	LBS.	0.00	0.00	0.00	0.00	0.00	0.00

URSIC New York/New Jersey - SIC 4924 C: Natural Gas - Residential, Commercial

SUMMARY OF LOSSES

		TOTAL	<5 LBS	5-25 LBS	26-100 LBS	101-400 LBS	>400 LBS
LOSSES	NO.	3[illegible]	2	6	2[illegible]	3	0
TO AIR	LBS.	1758.34	8.89	77.82	1152.75	518.88	0.00
LOSSES	NO.	3	3	0	0	0	0
TO LAND	LBS.	1.76	1.76	0.00	0.00	0.00	0.00
LOSSES	NO.	0	0	0	0	0	0
TO WATER	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES	NO.	0	0	0	0	0	0
TO EXPT	LBS.	0.	0.00	0.00	0.00	0.00	0.00
LOSSES	NO.	0	0	0	0	0	0
TO RECY	LBS.	0.00	0.00	0.00	0.00	0.00	0.00

URSIC New York/New Jersey - SIC 2951 C: Tars and Asphalt

SUMMARY OF LOSSES

		TOTAL	<5 LBS	5-25 LBS	26-100 LBS	101-400 LBS	>400 LBS
LOSSES	NO.	3[illegible]	9	24	0	0	0
TO AIR	LBS.	23[illegible].56	21.04	212.52	0.00	0.00	0.00
LOSSES	NO.	3[illegible]	0	5	15	13	0
TO LAND	LBS.	3179.43	0.00	77.06	1186.61	1913.7[illegible]	0.00
LOSSES	NO.	3[illegible]	7	25	1	0	0
TO WATER	LBS.	354.1[illegible]	17.20	305.84	3[illegible].07	0.00	0.00
LOSSES	NO.	0	0	0	0	0	0
TO EXPT	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES	NO.	0	0	0	0	0	0
TO RECY	LBS.	0.00	0.00	0.00	0.00	0.00	0.00

URSIC New York/New Jersey - SIC 2911 M: Refineries

SUMMARY OF LOSSES

		TOTAL	<5 LBS	5-25 LBS	26-100 LBS	101-400 LBS	>400 LBS
LOSSES	NO.	7	0	4	3	0	0
TO AIR	LBS.	216.50	0.00	60.50	156.00	0.00	0.00
LOSSES	NO.	7	0	4	3	0	0
TO LAND	LBS.	216.50	0.00	60.50	156.00	0.00	0.00
LOSSES	NO.	0	0	0	0	0	0
TO WATER	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES	NO.	0	0	0	0	0	0
TO EXPT	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES	NO.	0	0	0	0	0	0
TO RECY	LBS.	0.00	0.00	0.00	0.00	0.00	0.00

URSIC New York/New Jersey - SIC 2911 C: Fuel Oils

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SUMMARY OF LOSSES
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                        TOTAL         <5       5-25     26-100   101-40       >400
                                      LBS       LBS        LBS      LBS        LBS

LOSSES      NO.           33           0         2          5       21          5
TO AIR      LBS.     7360.03        0.00     46.25     279.52  4436.86  2597.40

LOSSES      NO.           33          33         0          0        0          0
TO LAND     LBS.        7.37        7.37      0.00       0.00     0.00       0.00


LOSSES      NO.            0           0         0          0        0          0
TO WATER    LBS.        0.00        0.00      0.00       0.00     0.00       0.00

LOSSES      NO.           29           3         9         17        0          0
TO EXPT     LBS.      936.60        6.70    108.90     821.00     0.00       0.00

LOSSES      NO.            0           0         0          0        0          0
TO RECY     LBS.        0.00        0.00      0.00       0.00     0.00       0.00
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URSIC New York/New Jersey - SIC 4091 C: Coal

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SUMMARY OF LOSSES
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                        TOTAL         <5       5-25     26-100  101-400       >400
                                      LBS       LBS        LBS      LBS        LBS

LOSSES      NO.           32          10        11          1        9          1
TO AIR      LBS.     3 64.47       25.38    111.87      86.13  1981.08  1160.01

LOSSES      NO.           32          21         6          4        1          0
TO LAND     LBS.      37 .83       15.25     89.75     139.94   128.89       0.00

LOSSES      NO.            0           0         0          0        0          0
TO WATER    LBS.        0.00        0.00      0.00       0.00     0.00       0.00

LOSSES      NO.            0           0         0          0        0          0
TO EXPT     LBS.        0.00        0.00      0.00       0.00     0.00       0.00

LOSSES      NO.            0           0         0          0        0          0
TO RECY     LBS.        0.00        0.00      0.00       0.00     0.00       0.00
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URSIC New York/New Jersey - SIC 3312 M: Coke Ovens

SUMMARY OF LOSSES

		TOTAL	<5 LBS	5-25 LBS	26-100 LBS	101-400 LBS	>400 LBS
LOSSES TO AIR	NO.	2	0	0	0	2	0
	LBS.	311.64	0.00	0.00	0.00	311.64	0.00
LOSSES TO LAND	NO.	2	0	1	1	0	0
	LBS.	59.36	0.00	21.28	38.08	0.00	0.00
LOSSES TO WATER	NO.	0	0	0	0	0	0
	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES TO EXPT	NO.	0	0	0	0	0	0
	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES TO RECY	NO.	0	0	0	0	0	0
	LBS.	0.00	0.00	0.00	0.00	0.00	0.00

URSIC New York/New Jersey - SIC 2.5 B: Caustic

SUMMARY OF LOSSES

		TOTAL	<5 LBS	5-25 LBS	26-100 LBS	101-400 LBS	>400 LBS
LOSSES TO AIR	NO.	0	0	0	0	0	0
	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES TO LAND	NO.	33	11	22	0	0	0
	LBS.	271.42	28.00	243.42	0.00	0.00	0.00
LOSSES TO WATER	NO.	33	2	11	20	0	0
	LBS.	1085.68	7.60	146.80	931.28	0.00	0.00
LOSSES TO EXPT	NO.	0	0	0	0	0	0
	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES TO RECY	NO.	0	0	0	0	0	0
	LBS.	0.00	0.00	0.00	0.00	0.00	0.00

URS

URSIC New York/New Jersey - SIC 3.0 : Other

SUMMARY OF LOSSES

		TOTAL	<5 LBS	5-25 LBS	26-100 LBS	101-400 LBS	>400 LBS
LOSSES TO AIR	NO.	33	0	5	16	12	0
	LBS.	28[illegible].53	0.00	69.39	902.15	1916.99	0.00
LOSSES TO LAND	NO.	33	0	2	6	20	5
	LBS.	7679.[illegible]	0.00	46.09	369.01	4312.6[illegible]	2951.93
LOSSES TO WATER	NO.	3	0	5	16	12	0
	LBS.	28[illegible].53	0.00	69.39	902.15	1916.9[illegible]	0.00
LOSSES TO EXPT	NO.	0	0	0	0	0	0
	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES TO RECY EXIT	NO.	3[illegible]	0	4	14	15	0
	LBS.	38[illegible]9.85	0.00	65.3[illegible]	891.75	26[illegible]2.76	0.00

URSIC New York/New Jersey - SIC 2812 : Chlor-alkali

SUMMARY OF LOSSES

		TOTAL	<5 LBS	5-25 LBS	26-100 LBS	101-400 LBS	>400 LBS
LOSSES TO AIR	NO.	1	0	0	0	0	1
	LBS.	4493.28	0.00	0.00	0.00	0.00	4493.28
LOSSES TO LAND	NO.	1	0	0	0	0	1
	LBS.	23923.68	0.00	0.00	0.00	0.00	23923.68
LOSSES TO WATER	NO.	1	0	0	0	1	0
	LBS.	303.60	0.00	0.00	0.00	303.60	0.00
LOSSES TO EXPT	NO.	0	0	0	0	0	0
	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES TO RECY	NO.	1	0	0	0	0	1
	LBS.	25016.64	0.00	0.00	0.00	0.00	25016.64

URSIC New York/New Jersey - SIC 2.5 A: Urethane

SUMMARY OF LOSSES

		TOTAL	<5 LBS	5-25 LBS	26-100 LBS	101-400 LBS	>400 LBS
LOSSES TO AIR	NO.	32	10	19	3	0	0
	LBS.	390.81	29.29	253.00	108.52	0.00	0.00
LOSSES TO LAND	NO.	33	0	9	21	3	0
	LBS.	1657.09	0.0	114.84	1108.18	434.08	0.00
LOSSES TO WATER	NO.	0	0	0	0	0	0
	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES TO EXPT	NO.	0	0	0	0	0	0
	LBS.	0.00	0.0	0.00	0.00	0.00	0.00
LOSSES TO RECY	NO.	0	0	0	0	0	0
	LBS.	0.00	0.00	0.00	0.00	0.00	0.00

URSIC New York/New Jersey - SIC 8021 : Dental

SUMMARY OF LOSSES

		TOTAL	<5 LBS	5-25 LBS	26-100 LBS	101-400 LBS	>400 LBS
LOSSES TO AIR	NO.	33	15	17	1	0	0
	LBS.	238.49	42.22	171.23	25.04	0.00	0.00
LOSSES TO LAND	NO.	0	0	0	0	0	0
	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES TO WATER	NO.	33	0	3	8	19	3
	LBS.	6000.70	0.00	60.06	540.07	3810.38	1590.19
LOSSES TO EXPT	NO.	0	0	0	0	0	0
	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES TO RECY	NO.	33	2	9	19	3	0
	LBS.	1454.01	8.73	136.68	923.28	385.31	0.00

URSIC New York/New Jersey - SIC 36292M: Tubes/Switches Manufacture

SUMMARY OF LOSSES

		TOTAL	<5 LBS	5-25 LBS	26-100 LBS	101-400 LBS	>400 LBS
LOSSES	NO.	19	16	2	1	0	0
TO AIR	LBS.	134.51	33.76	11.16	89.58	0.00	0.00
LOSSES	NO.	19	0	7	9	2	1
TO LAND	LBS.	2555.79	0.00	89.87	551.67	212.14	1702.12
LOSSES	NO.	0	0	0	0	0	0
TO WATER	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES	NO.	0	0	0	0	0	0
TO EXPT	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES	NO.	0	0	0	0	0	0
TO RECY	LBS.	0.00	0.00	0.00	0.00	0.00	0.00

URSIC New York/New Jersey - SIC 36410M: Lamp Manufacture

SUMMARY OF LOSSES

		TOTAL	<5 LBS	5-25 LBS	26-100 LBS	101-400 LBS	>400 LBS
LOSSES	NO.	21	19	2	0	0	0
TO AIR	LBS.	31.55	20.08	11.47	0.00	0.00	0.00
LOSSES	NO.	21	7	5	7	2	0
TO LAND	LBS.	599.45	25.27	68.97	287.28	217.93	0.00
LOSSES	NO.	0	0	0	0	0	0
TO WATER	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES	NO.	0	0	0	0	0	0
TO EXPT	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES	NO.	0	0	0	0	0	0
TO RECY	LBS.	0.00	0.00	0.00	0.00	0.00	0.00

URSIC New York/New Jersey - SIC 38291M: Control Instrument Manufacture

SUMMARY OF LOSSES

		TOTAL	<5 LBS	5-25 LBS	26-100 LBS	101-400 LBS	>400 LBS
LOSSES	NO.	16	11	5	0	0	0
TO AIR	LBS.	64.07	13.50	50.57	0.00	0.00	0.00
LOSSES	NO.	16	2	2	7	5	0
TO LAND	LBS.	1217.36	8.41	25.24	22[illegible].87	960.84	0.00
LOSSES	NO.	0	0	0	0	0	0
TO WATER	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES	NO.	0	0	0	0	0	0
TO EXPT	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES	NO.	0	0	0	0	0	0
TO RECY	LBS.	0.00	0.00	0.00	0.00	0.00	0.00

URSIC New York/New Jersey - SIC 36410C: Lamp Consumption

SUMMARY OF LOSSES

		TOTAL	<5 LBS	5-25 LBS	26-100 LBS	101-400 LBS	>400 LBS
LOSSES	NO.	32	0	8	15	9	0
TO AIR	LBS.	2[illegible]4[illegible].73	0.00	12[illegible].[illegible]1	783.26	15[illegible]8.67	0.00
LOSSES	NO.	3[illegible]	0	0	7	17	9
TO LAND	LBS.	10[illegible]38.64	0.00	0.00	45[illegible].60	4179.02	5425.3[illegible]
LOSSES	NO.	0	0	0	0	0	0
TO WATER	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES	NO.	0	0	0	0	0	0
TO EXPT	LBS.	0.00	0.00	0.00	0.00	0.00	0.00
LOSSES	NO.	0	0	0	0	0	0
TO RECY	LBS.	0.00	0.00	0.00	0.00	0.00	0.00

URSIC New York/New Jersey - SIC 36292C: Tubes/Switches Consumption

```
SUMMARY OF LOSSES
------- -- ------

                         TOTAL        <5       5-25    26-100   101-400      >400
                                      LBS      LBS       LBS       LBS       LBS

LOSSES     NO.            31          0        5        16         9         1
TO AIR     LBS.      2784.63        0.00     75.98    949.16   1346.96    412.53

LOSSES     NO.            33          0        0         4        14        15
TO LAND    LBS.     12693.27        0.00      0.00    237.23   3406.57   9049.47

LOSSES     NO.             0          0        0         0         0         0
TO WATER   LBS.         0.00        0.00      0.00      0.00      0.00      0.00

LOSSES     NO.             0          0        0         0         0         0
TO EXPT    LBS.         0.00        0.00      0.00      0.00      0.00      0.00

LOSSES     NO.             0          0        0         0         0         0
TO RECY    LBS.         0.00        0.00      0.00      0.00      0.00      0.00
```

URSIC New York/New Jersey - SIC 38291C: Control Instrument Consumption

```
SUMMARY OF LOSSES
------- -- ------

                         TOTAL        <5       5-25    26-100   101-400      >400
                                      LBS      LBS       LBS       LBS       LBS

LOSSES     NO.             0          0        0         0         0         0
TO AIR     LBS.         0.00        0.00      0.00      0.00      0.00      0.00

LOSSES     NO.            33          0        0         2        11        20
TO LAND    LBS.     27164.67        0.00      0.00    169.53 2841.3024213.84

LOSSES     NO.             0          0        0         0         0         0
TO WATER   LBS.         0.00        0.00      0.00      0.00      0.00      0.00

LOSSES     NO.             0          0        0         0         0         0
TO EXPT    LBS.         0.00        0.00      0.00      0.00      0.00      0.00

LOSSES     NO.            33          0        0         2         7        24
TO RECY    LBS.     32442.41        0.00      0.00    167.23 1812.3930462.80
```

URSIC New York/New Jersey - SIC 2851 C: Paint consumption

```
SUMMARY OF LOSSES
------- -- ------

                         TOTAL        <5        5-25      26-100    101-400     >400
                                      LBS        LBS        LBS        LBS       LBS

LOSSES     NO.             33         0          0          0          5         28
TO AIR     LBS.      48312.25       0.00       0.00       0.00 1163.7547148.50

LOSSES     NO.             33         0          7         18          8          0
TO LAND    LBS.       2542.75       0.00     106.75    1122.42 1313.58        0.00

LOSSES     NO.              0         0          0          0          0          0


TO WATER   LBS.          0.00       0.00       0.00       0.00       0.00       0.00

LOSSES     NO.              0         0          0          0          0          0
TO EXPT    LBS.          0.00       0.00       0.00       0.00       0.00       0.00

LOSSES     NO.              0         0          0          0          0          0
TO RECY    LBS.          0.00       0.00       0.00       0.00       0.00       0.00
```

URSCTY **New York/New Jersey, Queens County: Sector 3 (Unregulated) Sector 5 (Manufacturing and Processing) and Sector 8 (Final Consumption)**

```
FOR COUNTY  =QUEENS  AND BOX NOS.= 3 5 8

    TOTAL LOSSES TO LAND=        11995.42
    TOTAL LOSSES TO WATER=        1761.44
    TOTAL LOSSES TO AIR=         11107.71
    TOTAL LOSSES TO EXPORTS=        72.70
    TOTAL LOSSES TO RECYCLING=    2910.08
```

URSCTY **New York/New Jersey, Kings County: Sector 3 (Unregulated) Sector 5 (Manufacturing and Processing), and Sector 8 (Final Consumption)**

```
FOR COUNTY  =KINGS   AND BOX NOS.= 3 5 8

    TOTAL LOSSES TO LAND=        14757.13
    TOTAL LOSSES TO WATER=        2110.00
    TOTAL LOSSES TO AIR=         11986.77
    TOTAL LOSSES TO EXPORTS=        93.50
    TOTAL LOSSES TO RECYCLING=    3456.63
```

URSCTY **New York/New Jersey, Philadelphia County: Sector 3 (Unregulated) Sector 5 (Manufacturing and Processing) and Sector 8 (Final Consumption)**

```
FOR COUNTY  =PHILADE AND BOX NOS.= 3 5 8

    TOTAL LOSSES TO LAND=        16872.63
    TOTAL LOSSES TO WATER=        1709.56
    TOTAL LOSSES TO AIR=          8 90.95
    TOTAL LOSSES TO EXPORTS=         0.00
    TOTAL LOSSES TO RECYCLING=    5382.63
```

URSCTY New York/New Jersey, Bergen County: Sector 3 (Unregulated) Sector 5 (Manufacturing and Processing) and Sector 8 (Final Consumption)

```
FOR COUNTY  =BERGEN  AND BOX NOS.= 3 5 8

     TOTAL LOSSES TO LAND=          8029.90
     TOTAL LOSSES TO WATER=         1110.91
     TOTAL LOSSES TO AIR=           2878.94
     TOTAL LOSSES TO EXPORTS=         65.10
     TOTAL LOSSES TO RECYCLING=     1614.20
```

URSCTY New York/New Jersey, Queens County: Sector 3 (Unregulated)

```
FOR COUNTY  =QUEENS  AND BOX NOS.= 3

     TOTAL LOSSES TO LAND=           274.72
     TOTAL LOSSES TO WATER=           17.03
     TOTAL LOSSES TO AIR=           1783.75
     TOTAL LOSSES TO EXPORTS=         72.70
     TOTAL LOSSES TO RECYCLING=        0.00
```

URSCTY New York/New Jersey, Queens County: Sector 5 (Manufacturing and Processing)

```
FOR COUNTY  =QUEENS  AND BOX NOS.= 5

     TOTAL LOSSES TO LAND=           893.23
     TOTAL LOSSES TO WATER=          321.93
     TOTAL LOSSES TO AIR=            283.90
     TOTAL LOSSES TO EXPORTS=          0.00

     TOTAL LOSSES TO RECYCLING=      326.72
```

URSCTY New York/New Jersey, Queens County: Sector 8 (Final Consumption)

```
FOR COUNTY  =QUEENS  AND BOX NOS.= 8

     TOTAL LOSSES TO LAND=         10827.47
     TOTAL LOSSES TO WATER=         1422.47
     TOTAL LOSSES TO AIR=           9040.06
     TOTAL LOSSES TO EXPORTS=          0.00
     TOTAL LOSSES TO RECYCLING=     2583.37
```

URSCTY New York/New Jersey, Kings County: Sector 3 (Unregulated)

```
FOR COUNTY  =KINGS   AND BOX NOS.= 3

     TOTAL LOSSES TO LAND=          2[illegible]4.92
     TOTAL LOSSES TO WATER=           21.90
     TOTAL LOSSES TO AIR=           1138.08
     TOTAL LOSSES TO EXPORTS=         93.50
     TOTAL LOSSES TO RECYCLING=        0.0
```

URSCTY New York/New Jersey, Kings County: Sector 5 (Manufacturing and Processing)

```
FOR COUNTY  =KINGS   AND BOX NOS.= 5

     TOTAL LOSSES TO LAND=          987.49
     TOTAL LOSSES TO WATER=         362.11
     TOTAL LOSSES TO AIR=           318.49
     TOTAL LOSSES TO EXPORTS=         0.0
     TOTAL LOSSES TO RECYCLING=     361.31
```

URSCTY New York/New Jersey, Kings County: Sector 8 (Final Consumption)

```
FOR COUNTY  =KINGS   AND BOX NOS.= 8

     TOTAL LOSSES TO LAND=        1354[illegible].72
     TOTAL LOSSES TO WATER=        1725.98
     TOTAL LOSSES TO AIR=         10530.20
     TOTAL LOSSES TO EXPORTS=         0.0
     TOTAL LOSSES TO RECYCLING=    3095.32
```

URSCTY New York/New Jersey, Philadelphia: Sector 3 (Unregulated)

```
FOR COUNTY  =PHILADE AND BOX NOS.= 3

     TOTAL LOSSES TO LAND=          685.82
     TOTAL LOSSES TO WATER=          3[illegible].07
     TOTAL LOSSES TO AIR=          37[illegible]0.41
     TOTAL LOSSES TO EXPORTS=         0.0
     TOTAL LOSSES TO RECYCLING=       0.0
```

URSCTY New York/New Jersey, Philadelphia: Sector 5 (Manufacturing and Processing)

```
FOR COUNTY  =PHILADE AND BOX NOS.= 5

     TOTAL LOSSES TO LAND=          1130.55
     TOTAL LOSSES TO WATER=          322.36
     TOTAL LOSSES TO AIR=            284.90
     TOTAL LOSSES TO EXPORTS=          0.00
     TOTAL LOSSES TO RECYCLING=      311.33
```

URSCTY New York/New Jersey, Philadelphia: Sector 8 (Final Consumption)

```
FOR COUNTY  =PHILADE AND BOX NOS.= 8

     TOTAL LOSSES TO LAND=         15056.26
     TOTAL LOSSES TO WATER=         1354.13
     TOTAL LOSSES TO AIR=           4835.[illegible]
     TOTAL LOSSES TO EXPORTS=          0.00
     TOTAL LOSSES TO RECYCLING=     5071.30
```

URSCTY New York/New Jersey, Bergen County: Sector 3 (Unregulated)

```
FOR COUNTY  =BERGEN  AND BOX NOS.= 3

     TOTAL LOSSES TO LAND=           184.19
     TOTAL LOSSES TO WATER=           20.26
     TOTAL LOSSES TO AIR=            397.85
     TOTAL LOSSES TO EXPORTS=         65.10
     TOTAL LOSSES TO RECYCLING=        0.00
```

URSCTY New York/New Jersey, Bergen County: Sector 5 (Manufacturing and Processing)

```
FOR COUNTY  =BERGEN  AND BOX NOS.= 5

     TOTAL LOSSES TO LAND=           424.62
     TOTAL LOSSES TO WATER=          444.37
     TOTAL LOSSES TO AIR=            141.61
     TOTAL LOSSES TO EXPORTS=          0.00
     TOTAL LOSSES TO RECYCLING=      149.89
```

URSCTY New York/New Jersey, Bergen County: Sector 8 (Final Consumption)

```
FOR COUNTY  =BERGEN  AND BOX NOS.= 8

    TOTAL LOSSES TO LAND=         7421.09
    TOTAL LOSSES TO WATER=         646.29
    TOTAL LOSSES TO AIR=          2359.47
    TOTAL LOSSES TO EXPORTS=         0.00
    TOTAL LOSSES TO RECYCLING=    1464.31
```

URSLL for New York/New Jersey Region: Point Sources for Sectors I, II, III, and V

```
THE FOLLOWING LOCATION POINTS:

        41 DEG   0 MIN  LATITUDE          INCLUDE THESE COUNTIES:
        41 DEG  27 MIN  LATITUDE
        72 DEG  12 MIN  LONGITUDE          FAIRFIE NEWHAVE
        73 DEG  42 MIN  LONGITUDE



SUMMARY OF LOSSES
------- -- ------


                      TOTAL       <5       5-25     26-100   101-400     >400
                                  LBS       LBS       LBS       LBS       LBS

LOSSES     NO.          41         7        16         6         7         5
TO AIR     LBS.    7790.73     16.21    183.95    357.06   1159.69   6073.83

LOSSES     NO.          47        18         4         8        12         5
TO LAND    LBS.   12196.98     10.21     47.29    552.91   3231.45   8355.11

LOSSES     NO.          16         0         2         8         6         0
TO WATER   LBS.    1493.03      0.00     21.34    503.78    967.91      0.00

LOSSES     NO.           2         0         2         0         0         0
TO EXPT    LBS.      12.60      0.00     12.60      0.00      0.00      0.00

LOSSES     NO.          10         0         0         4         4         2
TO RECY    LBS.    5267.76      0.00      0.00    220.61    635.44   4411.71
```

URSLL for New York/New Jersey Region: Point Sources for Sectors I, II, III, and VI

```
 THE FOLLOWING LOCATION POINTS:

         40 DEG  42 MIN  LATITUDE     INCLUDE THESE COUNTIES:
         41 DEG   0 MIN  LATITUDE
         72 DEG  12 MIN  LONGITUDE     SUFFOLK NASSAU
         73 DEG  42 MIN  LONGITUDE




SUMMARY OF LOSSES
------- -- ------

                         TOTAL        <5        5-25     26-100   101-400     >400
                                      LBS        LBS       LBS       LBS       LBS

LOSSES    NO.              16          3          3         3         4          3
TO AIR    LBS.        5507.05      11.18      37.75    196.89    667.86  4593.36

LOSSES    NO.              19          4          3         5         3          4
TO LAND   LBS.        7941.86       1.76      34.28    343.75    816.19  6745.88

LOSSES    NO.               7          0          1         3         3          0
TO WATER  LBS.         887.50       0.00      10.07    206.83    670.61     0.00

LOSSES    NO.               1          0          0         1         0          0
TO EXPT   LBS.          43.00       0.00       0.00     43.00      0.00     0.00

LOSSES    NO.               5          0          0         2         2          1
TO RECY   LBS.        1354.91       0.00       0.00    147.80    442.60   764.51
EXIT
```

URSLL for New York/New Jersey Region: Point Sources for Sectors I, II, III, and V

```
THE FOLLOWING LOCATION POINTS:

      40 DEG  31 MIN  LATITUDE
      40 DEG  55 MIN  LATITUDE
      73 DEG  42 MIN  LONGITUDE
      74 DEG   4 MIN  LONGITUDE

INCLUDE THESE COUNTIES:

 NASSAU  QUEENS  KINGS   NEWYORK RICHMON WESTCHE HUDSON




SUMMARY OF LOSSES
------- -- ------

                      TOTAL       <5       5-25    26-100   101-400     >400
                                  LBS      LBS       LBS       LBS       LBS

LOSSES    NO.           67        11       11        12        19        14
TO AIR    LBS.    37463.67      13.97    168.16    567.20 3788.3332926.01

LOSSES    NO.           76        16       10        11        13        26
TO LAND   LBS.    50110.66      19.04    172.32    698.32 2227.9146993.07

LOSSES    NO.           31         0        4         6        17         4
TO WATER  LBS.     6245.78       0.00     63.76    387.52 3643.39 2151.11

LOSSES    NO.            4         0        0         4         0         0
TO EXPT   LBS.      272.20       0.00      0.00    272.20    0.00      0.00

LOSSES    NO.           20         0        0         2        12         6
TO RECY   LBS.     9827.22       0.00      0.00    175.03 2714.58 6937.61
```

URSLL for New York/New Jersey Region: Point Sources for Sectors I, II, III, and V.

```
   THE FOLLOWING LOCATION POINTS:

          39 DEG   55 MIN   LATITUDE        INCLUDE THESE COUNTIES:
          40 DEG   10 MIN   LATITUDE
          75 DEG    0 MIN   LONGITUDE         PHILADE
          75 DEG   18 MIN   LONGITUDE




  SUMMARY OF LOSSES
  ------- -- ------


                        TOTAL        <5       5-25     26-100   101-400     >400
                                     LBS       LBS       LBS       LBS       LBS

  LOSSES    NO.         19           0         4         6         4         5
  TO AIR    LBS.     8772.30       0.00     59.26    348.87    698.77   7665.40

  LOSSES    NO.         21           3         2         1         8         7
  TO LAND   LBS.    17251.29       0.83     43.32     62.00  1406.5415738.60

  LOSSES    NO.          7           0         0         2         3         2
  TO WATER  LBS.     1587.25       0.00      0.00    121.23    568.94    897.08

  LOSSES    NO.          0           0         0         0         0         0
  TO EXPT   LBS.        0.00       0.00      0.00      0.00      0.00      0.00

  LOSSES    NO.          5           0         0         0         3         2
  TO RECY   LBS.     5244.93       0.00      0.00      0.00    577.75   4667.18
```

URSLL for New York/New Jersey Region: Point Sources for Sectors I, II, III, and V.

```
THE FOLLOWING LOCATION POINTS:

      40 DEG  27 MIN  LATITUDE
      41 DEG   0 MIN  LATITUDE
      74 DEG   4 MIN  LONGITUDE
      74 DEG  48 MIN  LONGITUDE

INCLUDE THESE COUNTIES:

 ESSEX   HUDSON  MORRIS  PASSAIC UNION   SOMERSE BERGEN  MIDDLES DELAWAR




  SUMMARY OF LOSSES
  -----------------


                       TOTAL        <5       5-25     26-100   101-400      >400
                                    LBS       LBS        LBS       LBS       LBS

  LOSSES    NO.         125         23        38        33        23          8
  TO AIR    LBS.   18984.42      54.45    429.46   1739.89 3732.7313027.89

  LOSSES    NO.         143         31        16        32        29         35
  TO LAND   LBS.   76362.84      20.59    200.78   1814.69 6313.2168013.57

  LOSSES    NO.          70          1        13        32        24          0
  TO WATER  LBS.    7002.36       4.56    206.84   1771.87 5019.09       0.00

  LOSSES    NO.           7          0         1         6         0          0
  TO EXPT   LBS.     294.40       0.00     14.70    279.70      0.00      0.00

  LOSSES    NO.          36          0         3        18         8          7
  TO RECY   LBS.   32308.98       0.00     51.39   1039.18 1399.7629818.65
  EXIT
```

URSLL for New York/New Jersey Region: All Sources for Sectors I, II,.III, V, VIIIA, and VIIIB.

```
THE FOLLOWING LOCATION POINTS:

          41 DEG   0 MIN  LATITUDE          INCLUDE THESE COUNTIES:
          41 DEG  27 MIN  LATITUDE
          72 DEG  12 MIN  LONGITUDE          FAIRFIE NEWHAVE
          73 DEG  42 MIN  LONGITUDE




SUMMARY OF LOSSES
------- -- ------


                   TOTAL        <5       5-25     26-100   101-400     >400
                                LBS       LBS       LBS       LBS       LBS

LOSSES   NO.         27          6        11         6         3         1
TO AIR   LBS.   1824.12      15.37    120.62    357.06    613.79    717.28

LOSSES   NO.         31         18         3         4         5         1
TO LAND  LBS.   2989.01      10.21     31.42    285.76   1113.91   1547.71


LOSSES   NO.          8          0         2         4         2         0
TO WATER LBS.    486.37       0.00     21.34    221.19    243.85      0.00

LOSSES   NO.          2          0         2         0         0         0
TO EXPT  LBS.     12.60       0.00     12.60      0.00      0.00      0.00

LOSSES   NO.          2          0         0         0         2         0
TO RECY  LBS.    261.38       0.00      0.00      0.00    261.38      0.00
```

URSLL for New York/New Jersey Region: All Sources for Sectors I, II, III, V, VIIIA, and VIIIB.

```
THE FOLLOWING LOCATION POINTS:

      40 DEG  42 MIN  LATITUDE       INCLUDE THESE COUNTIES:
      41 DEG   0 MIN  LATITUDE
      72 DEG  12 MIN  LONGITUDE        SUFFOLK NASSAU
      73 DEG  42 MIN  LONGITUDE




SUMMARY OF LOSSES


                      TOTAL      <5        5-25     26-100    101-400    >400
                                 LBS       LBS        LBS       LBS       LBS

LOSSES     NO.         10         3         2          1         3         1
TO AIR     LBS.     2024.30     11.18     26.30      71.63    563.54   1351.65

LOSSES     NO.         12         4         3          4         1         0
TO LAND    LBS.      637.78      1.76     34.28     286.54    315.20      0.00

LOSSES     NO.          3         0         1          1         1         0
TO WATER   LBS.      163.42      0.00     10.07      34.80    118.55      0.00

LOSSES     NO.          1         0         0          1         0         0
TO EXPT    LBS.       43.00      0.00      0.00      43.00      0.00      0.00

LOSSES     NO.          1         0         0          0         1         0
TO RECY    LBS.      157.60      0.00      0.00       0.00    157.60      0.00
```

URS

URSLL for New York/New Jersey Region: All Sources for
Sectors I, II, III, V, VIIIA, and VIIIB.

```
THE FOLLOWING LOCATION POINTS:

          40 DEG  31 MIN  LATITUDE
          40 DEG  55 MIN  LATITUDE
          73 DEG  42 MIN  LONGITUDE
          74 DEG   4 MIN  LONGITUDE


INCLUDE THESE COUNTIES:

 NASSAU  QUEENS  KINGS   NEWYORK RICHMON WESTCHE HUDSON


SUMMARY OF LOSSES
------- -- ------

                   TOTAL      <5       5-25    26-100  101-400    >400
                              LBS      LBS       LBS      LBS      LBS

LOSSES   NO.         43       11         8         7       12        5
TO AIR   LBS.   6880.12    13.97    120.23    351.6[illegible] 2477.49 3916.78

LOSSES   NO.         48       16        10         9        7        6
TO LAND  LBS.   7322.65    19.04    172.32    526.72  1210.31  5394.27

LOSSES   NO.         15        0         4         6        5        0

 TO WATER LBS.   1474.46     0.00     63.76    387.52  1023.18     0.00

 LOSSES   NO.         4        0         0         4        0        0
 TO EXPT  LBS.    272.20     0.00      0.00    272.20     0.00     0.00

 LOSSES   NO.         4        0         0         0        4        0
 TO RECY  LBS.   1164.63     0.00      0.00      0.00  1164.63     0.00
```

URS

URSLL for New York/New Jersey Region: All Sources for Sectors I, II, III, V, VIIIA, and VIIIB.

```
THE FOLLOWING LOCATION POINTS:

        39 DEG  5[illegible] MIN  LATITUDE          INCLUDE THESE COUNTIES:
        40 DEG  10 MIN  LATITUDE
        75 DEG   0 MIN  LONGITUDE            PHILADE
        75 DEG  18 MIN  LONGITUDE


SUMMARY OF LOSSES
-- --- -- ------

                    TOTAL       <5       5-25      26-100    101-400    >400
                                LBS      LBS        LBS        LBS       LBS

LOSSES    NO.        12          0        3          2          4          3
TO AIR    LBS.    405[illegible].40       0.00     40.6[illegible]      63.94     698.77  32[illegible].13

LOSSES    NO.        13          3        2          1          6          1
TO LAND   LBS.   18[illegible]6.58       0.83     43.[illegible]      62.00    1087.56   [illegible]2[illegible].67

LOSSES    NO.         3          0        0          2          1          0
TO WATER  LBS.    35[illegible].43       0.00      0.00    121.[illegible]3     234.20      0.00

LOSSES    NO.         0          0        0          0          0          0
TO EXIT   LBS.      0.00       0.00      0.00       0.00       0.00      0.00

LOSSES    NO.         1          0        0          0          1          0
TO RECY   LBS.    31[illegible].3       0.00      0.00       0.00     31[illegible].3[illegible]      0.00
```

URS

URSLL for New York/New Jersey Region: All Sources for Sectors I, II, III, V, VIIIA, and VIIIB.

```
THE FOLLOWING LOCATION POINTS:

        40 DEG  27 MIN  LATITUDE
        41 DEG   0 MIN  LATITUDE
        74 DEG   4 MIN  LONGITUDE
        74 DEG  48 MIN  LONGITUDE




INCLUDE THESE COUNTIES:

 ESSEX   HUDSON  MORRIS  PASSAIC UNION   SOMERSE BERGEN  MIDDLES DELAWAR




SUMMARY OF LOSSES
------- -- ------


                     TOTAL        <5       5-25     26-100   101-400     >400
                                 LBS        LBS        LBS       LBS      LBS

LOSSES    NO.           83        20         26         19        17        1
TO AIR    LBS.     8621.78     40.20     274.70     913.37   2900.23  4493.28

LOSSES    NO.           94        31         13         20        16       14
TO LAND   LBS.    41623.07     26.59     142.85    1082.72   3163.5137207.62

LOSSES    NO.           42         1         11         16        14        0
TO WATER  LBS.     4776.52      4.56     169.84     806.01   3796.11     0.00

LOSSES    NO.            7         0          1          6         0        0
TO EXPT   LBS.      294.40      0.00      14.70     279.70      0.00     0.00

LOSSES    NO.            8         0          0          5         2        1
TO RECY   LBS.    25685.12      0.00       0.00     376.69    291.7925016.64
```

APPENDIX D

GENERAL METHODOLOGY

The development of a general methodology for the project involved two tasks. The first was to determine the quantity of mercury used and subsequently lost to the environment by a particular user. The second task was to determine the distribution of the expended mercury, in whatever form, to any or all of the following categories: air, land, water, recycling.

Data on general use of mercury by some consumers was rather easy to obtain. For instance, the Bureau of Mines has reliable figures on mercury used by the dental profession, electrical apparatus industry, and paint industry. However, emissions of unregulated sources such as fossil fuel combustion and incineration are difficult to quantify.

Another problem arises in determining how much of the mercury used actually enters the environment and at what step in the process. For example, in paint manufacture the preservative used in the paint (phenylmercuric acetate, or PMA) is manufactured at one site and the paint is formulated at another and is applied at yet other locations. At each of these steps mercury is lost in one form or another. In the first step (PMA manufacture), close scrutiny and regulation of the industry which manufacturees this chemical and other mercurials have reduced emissions to insignificant quantities. The same is true of the paint formulation stage. Once the paint is applied, some of the PMA vaporizes from the coated surface and enters the air, and this amount must be estimated. Therefore, Table 7 of the main body of this report has a column which represents the total mercury available to that process or use which could potentially be lost to the environment. The next column, however, illustrates what proportion of this available mercury actually does enter the environment (or is recycled).

The figures in Table 7 represent national totals; when looking at a particular section of the country, a proportion of some sort must be applied to estimate the usage within the region of interest. For this purpose population proportions, a manufacturing employment ratio, or a multifactor ratio were used. A manufacturing employment ratio is the total number of people employed in manufacturing in the region divided by the national total. The multifactor ratio is similar to the manufacturing employment ratio except that it also includes wholesale and retail trade, services (including education), and government employment. These ratios are applied to the national usage to obtain a total for the study region. This total is then distributed within the region by the ratio of the county (or appropriate area) total to this regional total. Such a methodology was used, for example, for many of the consumption categories in Sectors VIIIA and VIIIB. In other cases, specific plants or emitters could be located and mercury emission data could be obtained. Examples are chlor-alkali plants and the manufacture of products containing or needing mercury.

Once total mercury usage for a particular use within a particular geographical area was determined, the second task was to distribute this mercury to air, land, water, or recyling. This task required the establishment of emission factors. Such factors were determined in a number of ways. The primary source was published data or information. In some cases these data proved incorrect and appropriate changes were made where necessary. In other cases, plant visits and oral and written correspondence were used. This method was used successfully in evaluating the chlor-alkali industry. Also, materials balance flow diagrams were constructed to assist in verifying the derived emission factors.

Other sources of information initially believed to be valuable were found to be completely useless. For example, a permit application list of potential mercury emitters, by EPA region, was found to contain spurious data, as the list was hurriedly compiled and consequently the methodology and analysis were very poor. In fact, much of the data was recorded in the wrong units.

Both man-made and natural losses are covered in the methodology used for this study, as each is important in determining where, how much, and in what form mercury is released to the environment. Most emitters were classified by an SIC (Standard Industrial Classification) code as an aid in identifying sources.

Following are descriptions of how each source of mercury emissions was considered. For more detailed explanations of some source categories, the reader is referred to the section on Technology Assessment.

MERCURY MINING (SIC 1092M) AND PROCESSING (SIC 1092P)

Most active mercury mines are located in California or Nevada; together, these states account for 88 percent of the present national production. Mines in each region were identified and the total mercury mined was determined (Ref. 110). Losses of mercury during the mining process are very trivial (Ref. 12) and result primarily from the dust produced in extracting the ore.

Most mercury emissions occur during processing of ore to recover elemental mercury. The ore must go through a smelting operation in which mercury becomes volatilized and is therefore lost to the air. The overall loss of mercury is approximately 9 percent (Ref. 111), but it may be as much as 20 percent or as little as 5 percent, depending upon recovery methods employed at the facility. Emission standards are not presently tied to the volume of ore processed, but to daily maximum release rates.

LIME PRODUCTION (SIC 3274)

The mining and processing of limestone ore cause very little mercury to be released to air, water, or land, as the concentrations of mercury in the ore is small.

CEMENT PRODUCTION (SIC 3241)

Cement manufacture is another relatively small source of mercury emissions (Ref. 112) that derives from the mining and processing of clay limestone to produce cement. Emissions accrue primarily to land, as collected dust is disposed of in landfills. Mercury concentrations at the kiln stack range from 0.0047 to 0.0082 ppm by volume.

COPPER SMELTING (SIC 3331) AND MINING (SIC 1021)

Copper smelters are a major source of mercury emissions to the environment. Copper mining is an additional, but smaller, source. In determining mercury emissions from these sources, a number of paths were pursued General disagreement among literature sources (Refs. 113-115) prompted us to telephone selected smelter operations in order to obtain more accurate information on the ores smelted and copper recovered. Once figures were established on the amount of copper produced, an emission factor of 0.011 pound of mercury released per ton of concentrate processed was applied (Ref. 12). This increases to 0.055 pound of mercury per ton of copper produced, as there is a concentration factor of 5 in going from the concentrated ore to the metal (Ref. 113). The emission factor is then multiplied by the amount of copper produced by a given smelting operation (Refs. 113, 114) and the mercury released is apportioned to air, water, and land; the principal emissions, of course, are to air.

Very small -- almost negligible -- amounts of mercury are lost during the mining of copper ore.

ZINC AND LEAD MINING (SIC 1031)

Because zinc and lead are normally found in the same deposit, the two minerals are mined together. Some mercury is lost in minute quantities as a result of the mining process. However, this loss is trivial and of little concern.

LEAD AND ZINC SMELTING (SIC 3322 AND 3333)

Mercury contained in lead and zinc ores is volatilized during the smelting process. Although not as important as copper smelting as a source of mercury, these processes nevertheless contribute a significant quantity. The various plant locations and production rates were found from the Minerals Yearbook (Ref. 116).

AGRICULTURAL USES (SIC 2879A), LIVESTOCK (SIC 021), AND NONFARM PESTICIDES (SIC 2879N)

The agricultural uses of mercury are primarily as seed dressings. The nonagricultural sources of mercury emissions include such things as golf course and commercial turf fungicide applications. Livestock losses are from animal manures.

Mercury lost from animal manures was determined from Census of Agriculture data by county, and emissions from agricultural seed dressings were estimated using data on purchased seed, by type, for farms with cash sales of $2,500 per year and over (Ref. 117). These large farms account for a significant proportion of the total. A ratio of 0.142 pound of mercury per thousand tons of feed (based on 50-percent recycle of manures) was applied to these annual tonnage figures in order to calculate mercury loss.

Data on agricultural pesticide use come from the U.S. Department of Agriculture and the U.S. Bureau of Mines. Personal contacts with various state, EPA, and Department of Agriculture personnel, as well as with plant pathologists and pesticide distributors, gave us the information needed to estimate the distribution of mercurials used for seed treatment. The estimates of distribution of mercurials to water and land were also based on information secured from these contracts.

The remainder of the pesticides are assumed to be used for nonagricultural purposes. The multifactor ratio was used to allocate usage within a defined region. As these chemicals are topically applied, emissions are to air as well as to land and water. All mercury lost from livestock manures is assumed to go to land.

COAL-BURNING POWER PLANTS (SIC 49110) AND OTHER (SIC 4091C)

Electric utilities consume 67 percent of the coal used in the United States. All coal consumed within a study region was assumed to be mined in or near that area (Ref. 49). (For example, coal consumed in California was assumed to come from Montana, Colorado, Arizona, or Utah.) The mercury concentration assumed for coal is an average of the concentrations found in coals adjacent to the area in question (Refs. 51, 54, 118, 119).

Coal consumed by households and by the commercial, industrial, and transportation sectors was apportioned on a population basis for geographical regions within states.

Power plants that use coal were located geographically and the coal consumed by each was determined (Ref. 49). The average concentration of the mercury in the coal was then used to obtain figures on total mercury loss from this sector of the economy. The mercury lost during combustion is primarily to air. However, some remains in the fly ash, bottom ash, and water settling ponds; disposal of this portion is to land. As temperatures within a power plant boiler (800°F) are higher than the boiling point of mercury (685°), the majority of the mercury lost is in the form of the vaporized metal or mercuric oxide. With this in mind, proportional mercury losses to air and land were determined (Refs. 12, 52, 120, 121).

NATURAL GAS COMBUSTION -- RESIDENTIAL, COMMERCIAL, INDUSTRIAL (SIC 4924C), AND UTILITIES (SIC 49110)

The same method used in determining coal usage within a particular region was also used for natural gas. Natural gas consumed for electric power generation was assigned to the SIC 49110 group and the remainder to SIC 4924C. Adequate backup data were lacking, but the mercury concentrations was assumed to be 0.04 ppm (Ref. 12).

Because natural gas burns very cleanly and with a very high (theoretical) flame temperature (3,700°F), the bulk of the mercury is lost to air, primarily as the metal but with slight emissions as the metallic oxide. However, evidence indicates that some of the metallic mercury in natural gas will combine with sour gas (H_2S) and precipitate onto pipeline walls (Refs. 121, 122). Mercury may be lost to land as pipe or fittings are replaced, but in only minor amounts. Therefore, total losses have been assigned to air, with a minute quantity to land.

PETROLEUM (SIC 2911C)

There are varying grades of fuel oils, each with correspondingly varying amounts of mercury. Light distillates, because of their low flame temperatures, are assumed to release insignificant amounts of mercury. Distillate-type oils are found to contain 0.066 ppm (Ref. 12) and residual oils 0.13 ppm (Ref. 123). A mass balance was performed to determine the remaining mercury in tars and asphalt (Ref. 124), and the mercury concentration of these by-products was estimated to be 0.7 ppm. Total petroleum usage within a given region is determined employing the same methodology as that used for coal and natural gas.

Mercury losses from the combustion of petroleum fuels are primarily to air. Because the flame temperature of most fuels is above the boiling point of mercury, the mercury is lost chiefly as the metal or metallic oxide.

REFINERIES (SIC 2911M)

Mercury losses from refineries can be expected to occur at oil sludge ponds, from spillage, and from burning of waste materials. This loss is assumed to be 5 percent (URS estimate) of all the mercury contained in the crude oil. The amount of crude oil processed at a particular plant is found (Ref. 125) and the total amount of mercury lost is determined. Little is known about these internal plant losses, so factors were arbitrarily applied and emissions were assigned to air and land.

TARS AND ASPHALT (SIC 2951C)

Tar and asphalt mercury loss is a complex matter, because an initial loss during application (normally to air) occurs and then there is a gradual loss due to erosion. The 5-percent figure for initial loss to air is based on current consumption data (Ref. 126), whereas the gradual loss is based on a life span of 30 years for tar- and asphalt-paved surfaces. Erosion of the surface due to use and rainfall will cause some of the mercury to go to water, with the remainder finding its way to land from further erosion, street cleaning, etc. The majority of the mercury loss to air is in an organic form or as mercury oxide, because of the low melting point of tar and asphalt. Losses to both water and land are in organic forms only. In our study the mercury loss was distributed on a population basis, the assumption being that usage of tars and asphalts correlates satisfactorily with this factor.

DENTAL APPLICATIONS (SIC 8021)

Mercury is used as an amalgam in dental filling preparations. Total national use was apportioned to a given region on the basis of population. It has been determined that approximately 75 percent of the mercury used in dental preparations remains in the teeth (Ref. 12) and will not reach the environment. Primary losses are to water, with the remainder to air (volatilization) and recycling (Ref. 12).

CONTROL INSTRUMENTS (SIC 3291M AND 38291C)

Mercury is used in flowmeters, thermometers, barometers, and similar devices. Total national use was determined by comparing various sources (Refs. 121, 125). Approximately 1 percent of this mercury is lost during manufacture of the instruments. Some mercury-containing instruments are brought into the country, while others are exported, and this net transport was also accounted for. The resulting total was multiplied by the manufacturing employment ratio for a region and this figure was apportioned to land and recycle for final consumption. (All losses during manufacture are assumed to go to an industrial landfill.)

Plants that manufacture control instruments in a given study region were located by field contacts and through a survey of the literature. Employment at each plant was divided by national employment for the particular SIC category. This ratio was multiplied by total manufacturing losses to arrive at the plant's emissions to air, land and water.

BATTERIES (SIC 2642M AND 3642C)

Mercury is used in a number of types of batteries. National usage was determined from various sources and was adjusted for imports, exports, and losses.

During manufacture of batteries approximately 0.5 percent of the mercury used is lost. Most of this loss is to land, with smaller amounts to air and water (Ref. 69). We assumed that 5 percent of the batteries disposed of in this country are incinerated; an adjustment to this figure was made wherever a significant difference in solid waste disposal methods was found. For example, New York City incinerates approximately 40 percent of its solid waste, thereby putting more mercury into the air than would otherwise be lost to land.

TUBES AND SWITCHES (SIC 3629C AND 3629M)

Power tubes, rectifiers, relays, and switches are mercury-consuming devices that contribute to environmental losses of the metal. The method used to determine these losses was similar to that for batteries and controls, in that national totals were derived and appropriate adjustments were made for imports, exports, and manufacturing losses (Refs. 24, 25). Consumptive losses in a given region of the United States were arrived at by using the manufacturing employment ratio. All tubes and switches were assumed to end up eventually in landfills (with some undoubtedly being incinerated, in which case mercury would be emitted to the air).

Manufacturing losses are quite trivial; the assumption is that approximately 2.5 percent of the devices rejected are not recycled and disposed of in an industrial landfill.

CATALYSTS AND MISCELLANEOUS COMPOUNDS (SIC 2819M, 2851M, 2879M)

The three SIC codes shown above refer to a group of chemical manufacturers who produce compounds which are precursors for use as catalysts and in paint and pesticides. The location of the manufacturers and types of mercurial chemicals produced are rather easily obtained (Ref. 62). However, it is difficult to allocate actual mercury usage and concomitant losses. From a knowledge of the relative size of the plant and maximum allowable discharge rates, approximations can be made with regard to mercury loss. From plant visits and correspondence, it was found that actual losses are less than 0.1 percent of the mercury used.

Bureau of Mines data were used to sum total mercury usage by the paint and pesticide industries as well as for catalysts. By applying the 0.1 percent loss, total mercury losses for this group of manufacturers can be estimated.

CHLOR-ALKALI (SIC 2812)

Sources of data regarding mercury consumed and lost within the chlor-alkali industry included various Bureau of Mines publications, as well as actual plant visits. In the case of the Bureau of Mines data, only a national total for the industry's mercury use is given. Therefore the national total was multiplied by the ratio of SIC 2812 employment in mercury cell plants in each study area to the national employment in SIC 2812.

The Ref. 14 data on emissions were used, as they pertain to mercury consumption by specific plants. To validate the procedures used and to obtain some specific figures, visits were made to certain plants (PPG Plant in Lake Charles, Louisiana, and the BASF Wyandotte Plant, Port Edwards, Wisconsin). These visits revealed that as much as 68 percent of the mercury used may be unaccounted for. It is of major concern, we feel, that so much mercury is apparently vanishing. The chlorine manufacturers are aware of this problem and are making strides toward greater accountability, but so far have not achieved total material balances.

The mercury that is lost escapes to air (hydrogen stream and end box ventilation), water (brine water), land (disposal of sludges), and a small portion (0.42 - 0.50 percent) into product (caustic). The values shown in text Table 7 represent an average loss from all U.S. plants. Where specific information regarding losses could be obtained, this was used in lieu of the averaged data. Other adjustments were made for age of plant, total chlorine produced, and history of operation.

LABORATORY USES (SIC 7391)

Mercury use within a given region is, of course, a proportion of national use (Ref. 12). This proportion was calculated using an American Chemical Society list of laboratories in a given region for which the information was considered adequate. However, for most regions, the figures obtained were judged to be out of balance with the likely levels of use. For these regions the multifactor ratio was used, because it corresponds more logically with the probable distribution of both school and industrial laboratories where mercury would be used and lost.

Mercury losses to the environment from laboratory usage have been greatly reduced in the last few years. Therefore, in contrast to the assignment given in Ref. 12, we have assigned the greatest proportion of the mercury balance to recycling.

PHARMACEUTICALS (SIC 2933M AND 2834C)

Mercury losses during pharmaceuticals manufacture are confined almost exclusively to Baltimore, Maryland; Chicago, Illinois; Indianapolis, Indiana; and the State of New Jersey. New Jersey alone contains approximately 80 percent of the U.S. plants that produce mercurial pharmaceuticals. The total consumption of these mercurials in a given study region was prorated from national figures and distributed on a population basis. Some small error was introduced in this procedure in that veterinary uses are not specifically known and could not be assigned.

During the manufacture of mercury-containing drugs, only about 0.1 percent of the total mercury is lost. Therefore, the bulk of the mercury used in pharmaceuticals is lost during bathing (in the case of an externally applied cosmetic or medicine), and for an internally applied drug mercury is excreted in the urine. Essentially all the mercury is therefore lost to water.

PAINT (SIC 2851F AND 2851C)

Mercury, usually in the form of phenylmercuric acetate (PMA), is used in paints as a preservative and mildewcide. Mercury losses during manufacture are very trivial (0.25 percent of the PMA used). However, during and after application, approximately 65 percent of the mercury becomes vaporized--most of it within the first 24 hours after application. Another 5 percent is assumed to remain in the can and to end up ultimately in a landfill.

Total national mercury use in paints was determined from Bureau of Mines figures; for regional distribution, the multifactor ratio was used. The emission factors for paint formulation were assumed to be almost equally divided between air and water, and application losses were assumed to be primarily to air.

OTHER (SIC 3.0)

This category includes mercury used in miscellaneous products such as pump seals, together with chemicals not specifically addressed elsewhere. Total national usage of mercury in this category was estimated using Ref. 12, and URS applied the multifactor to determine regional totals and to establish apportionments with regions.

URETHANE PRODUCTION (SIC 2.5A) AND FOAM CAUSTICS (2.5B)

The use of mercury as a catalyst in urethane production was determined from national totals. Of the total reported by the Bureau of Mines, approximately two-thirds goes into urethane foam manufacture and the other one-third into vat dyes. A regional proportion was assumed simply in terms of the population percentage of the area, because the urethanes are used primarily as a soundproofing agent in walls. Distribution of mercury to the appropriate environmental parameters was based on the means of solid waste disposal of these foam products.

Caustic (sodium hydroxide), recovered as a by-product of the chlorine manufacturing process, is used in the manufacture of a number of products, particularly foams. Mercury is contained as a trace contaminant (4 ppm) and therefore finds its way into the foam, and is lost primarily to water. The mercury lost was distributed within regions on a manufacturing basis.

LAMPS (SIC 36410M AND SIC 36410C)

Each fluorescent lamp contains approximately 50 mg of mercury (Ref. 127). About 4.6 percent of the mercury consumed nationally is used in the electrical and control instrument industries. Proper adjustments were made for imports and exports to arrive at consumptive losses, most of which are to land, with a slight amount to air if spent bulbs reach the municipal waste. The manufacturing employment ratio was used to obtain regional totals and accomplish the apportionment. Approximately 4 percent of the lamps are assumed to be rejected during manufacture, with approximately 5 percent of the mercury lost to air due to vaporization during testing, and the remainder going to industrial landfills.

GOVERNMENT USAGE (SIC 9199)

Two of the largest government consumers of mercury are the Atomic Energy Commission (AEC) and the Department of Defense (Ref. 82). Much of this use is for reprocessing spent nuclear fuel. Because it is very difficult to obtain information regarding mercury use by these and similar agencies, approximations were made. For example, in the Kentucky-Tennessee study region, a fractional proportion of the total U.S. mercury use was assigned to the military installations there, based on the military population of each state. In the case of Oak Ridge National Laboratory (ORNL), assumptions were made concerning its potential mercury losses. It was assumed that ORNL uses 5 percent of the U.S. total consumed by the AEC. It was also assumed that

4 percent of this is lost to the environment, of which 30 percent goes to water and 70 percent to land. This was purely a conjectural attempt to account for mercury used by this sector of our economy, and our figures are, of course, subject to revision.

DEGASSING

The calcultion of natural degassing rates was based on work performed by others and on observations and assumptions developed in this study. Various workers have developed both global and regional degassing rates. These data are summarized in text Table 8.

These observations and calculations indicate that: (1) the average land degassing rate is probably 0.2 $\mu g/m^2/day$; (2) degassing rates higher than the average are associated with mineralized deposits; (3) over aqueous sediments high in mercury, the degassing rate is probably higher than over land; (4) the ratio between global land and ocean degassing rates is unknown, but MacKenzie's assumption of equality is probably adequate. Using these concepts, URS calculated a probable national degassing rate. The assumptions for these calculations are summarized below:

1. The base national degassing rate was assumed to be 0.2 $\mu g/m^2/day$.
2. For moderately mineralized areas, a degassing rate of 0.4 $\mu g/m^2/day$.
3. For highly mineralized areas and known mercury deposits, a 0.8 $\mu g/m^2/day$ was assumed.

For the purposes of differentiating between areas, text Figure 9, which indicates general areas of known mercury and mineralized deposits, was used. Using the degassing rates and the total surface area (both land and water) for each state, a state-by-state inventory of total annual degassing was made. On a national basis, the annual degassing rate was estimated to be about 1 million kg per year, equivalent to a national unit rate of 0.36 $\mu g/m^2/year$.

The other contribution from natural sources, that of erosion, was determined by calculating the average annual runoff from each state and multiplying this figure by the average statewide sediment concentration (Ref. 128). The total annual sediment load was multiplied by the average sediment mercury concentration of 71 ppb (Ref. 29). These state-by-state totals were then summed for the national inventory. This amounted to about 200,000 kg per year. An attempt was also made to determine the contribution from urban runoff. According to this calculation, urban runoff contributes about 10,000 kg per year to the nation's waters, or about 5 percent of that from soil erosion. Therefore, on an areal basis, the contribution of urban sources is about four times higher than that of natural sources (but urban areas represent only about 1.2 percent of the total land area).

Runoff

Runoff contributions were calculated by performing a surface water balance on major streams within each region. The resulting net flow rate was then multiplied by 1 ppb (an average mercury content of most major streams) to determine the average mercury input rate.

Solid Waste

Information on the disposal of solid waste was obtained from personal communications with state and federal solid waste management personnel. This information, coupled with average values for mercury in solid wastes, was utilized in distributing mercury losses due to incineration in various regions.

Groundwater

Very little information is available on mercury concentrations in groundwater, but the most widely quoted value is 0.05 ppb. This is a reasonable figure, because the general high adsorptive capacity of soils doubtless reduces mercury concentrations as water percolates to the water table. Data on quantities of groundwater withdrawn in a given region were taken from USGS publications on water supply for individual states. The yearly quantity of mercury was obtained by applying a list of conversion factors to these values.

Septic Tanks

The amount of mercury lost to land from septic tanks was calculated by first assuming an average mercury content of 2 ppb in the sewage (Ref. 12). The total water volume was determined by subtracting from the total population of a region the number of people served by municipal treatment systems and multiplying the result by 75 gallons per capita per day (average loading from single family residences). There is also some loss of mercury to land due to irrigation, leaks, and so on. The amount depends on the region, but these increments are trivial.

Sewage

Data were obtained on mercury lost in disposal of sewage and sludge by municipal water users. The total net output of mercury was calculated by subtracting the mercury input from water supply and the mercury output expected from sewage treatment plants. Mercury quantities in various flows were calculated by multiplying the mercury concentration and water quantity data using appropriate conversion factors.

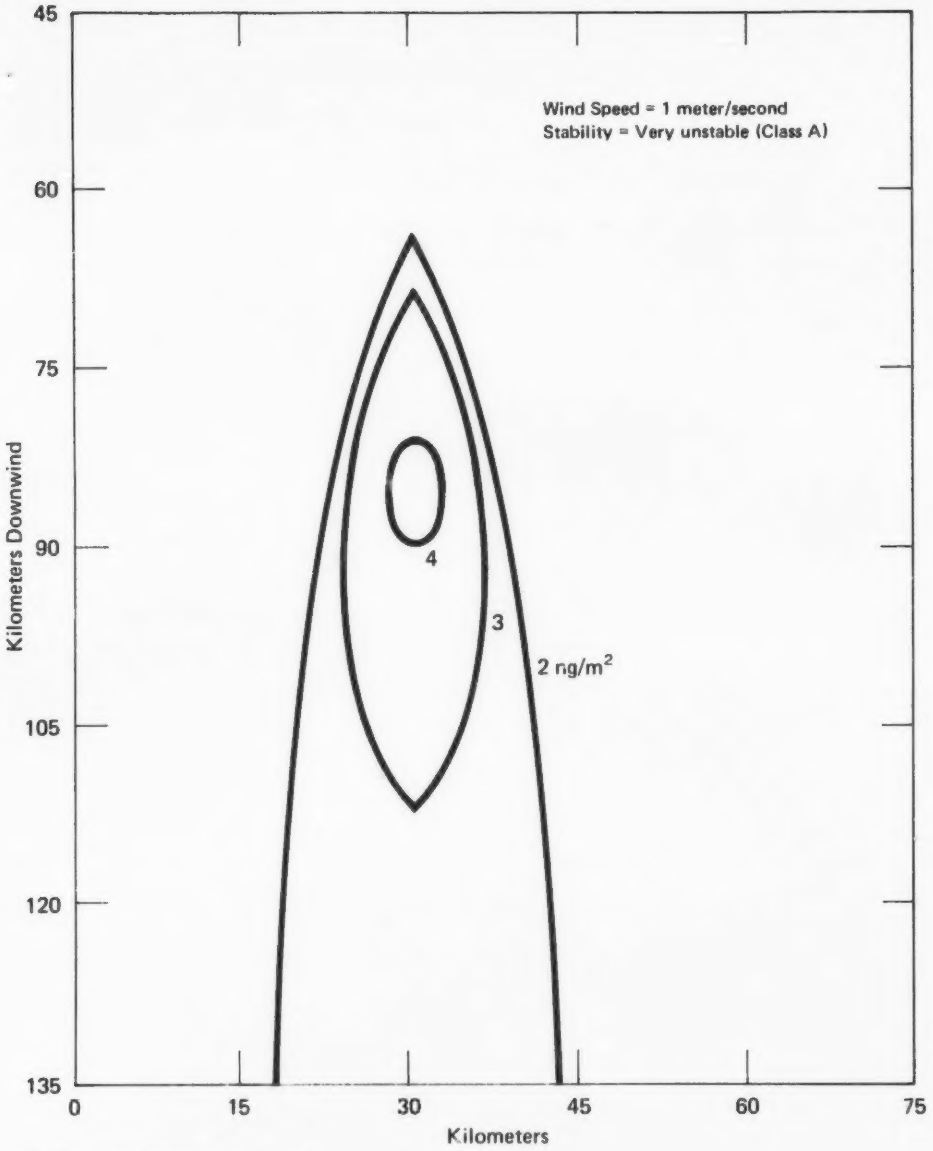
APPENDIX E

POINT SOURCE EMISSIONS OF MERCURY

Two primary sources of mercury vapor that enters the atmosphere are coal-fired power plants and copper smelters. Such sources may subsequently also contribute to relatively high ground level concentrations. With this in mind, dispersion analyses were performed for a large coal-burning power plant for which mercury emissions data were available, and for a copper smelter.

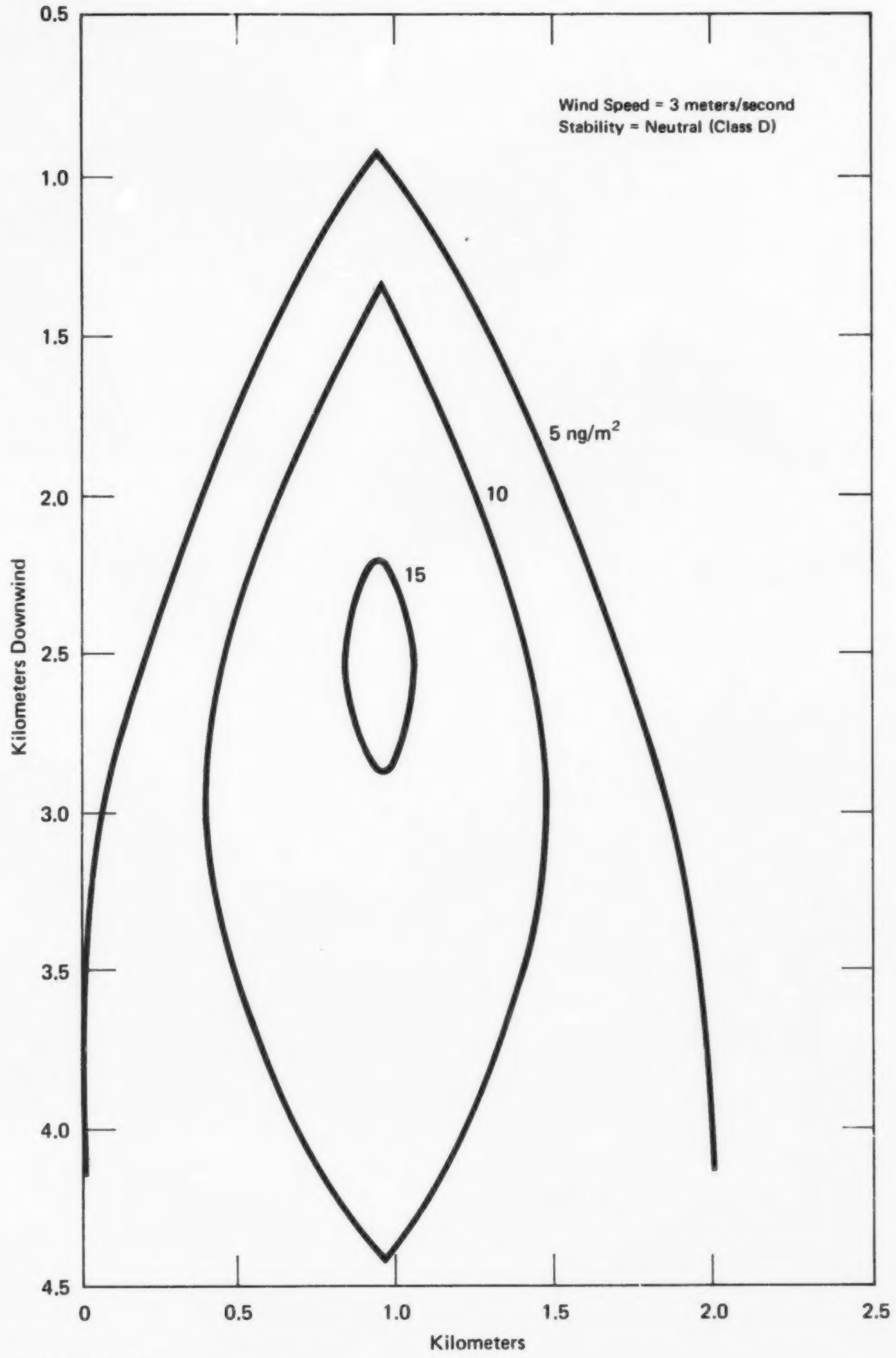
Figures E-1 through E-3 are isopleths of mercury vapor concentrations which result from a copper smelting operation in Arizona. Three cases were analyzed for mercury vapor concentration: (a) adverse meteorological conditions (very unstable and 1 meter per second wind speed) and an 8-hour averaging time; (b) average meteorological conditions (neutral stability and 3 meters per second wind speed) and a 3-minute averaging time; (c) adverse meteorological conditions (very unstable and 1 meter per second wind speed) and 3-minute averaging time. The three cases were run to compare with the occupational eight-hour average, and to determine what short-term concentration might exist under average and adverse conditions. The highest concentration (∿40 $\mu g/m^3$) occurs in Case 3, where the averaging time is shortened and the meteorological conditions are most conducive to producing high ambient levels.

Case 4 (Fig. E-4) pertains to a large coal-burning power plant (∿12,000) tons of coal consumed per day). Stack gas concentrations of mercury were determined to be approximately 18 $\mu g/m^3$. (This compares to a concentration of approximately 167 $\mu g/m^3$ in the stack gases of the copper smelters.) The maximum concentration generated from two stacks (300 and 500 feet is 7 $\mu g/m^3$ -- well below any dangerous levels.



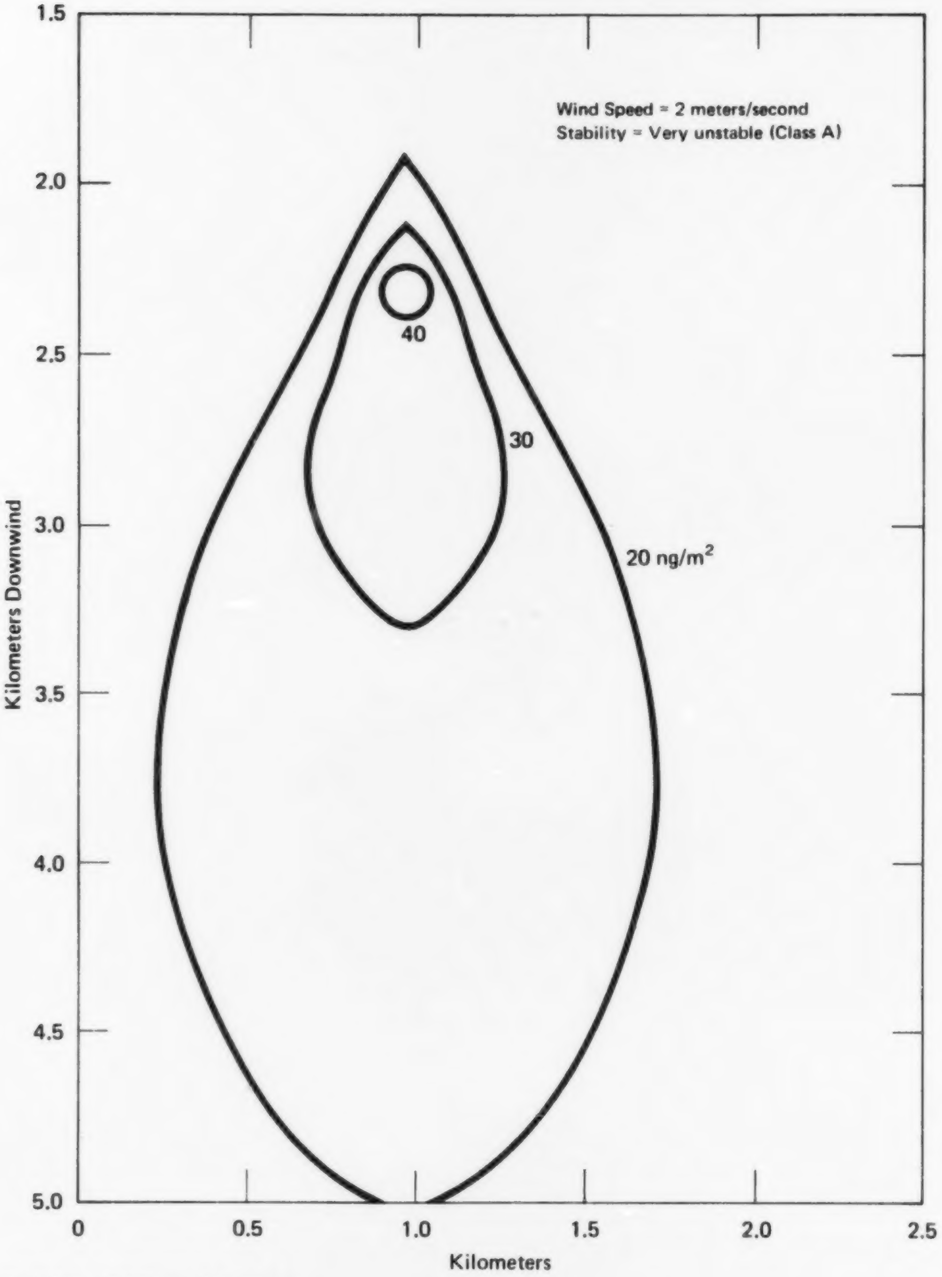
SOURCE: URS Research Company.

Figure E-1 CASE 1: COPPER SMELTER MERCURY VAPOR CONCENTRATION UNDER ADVERSE METEOROLOGICAL CONDITIONS (8-hour average)



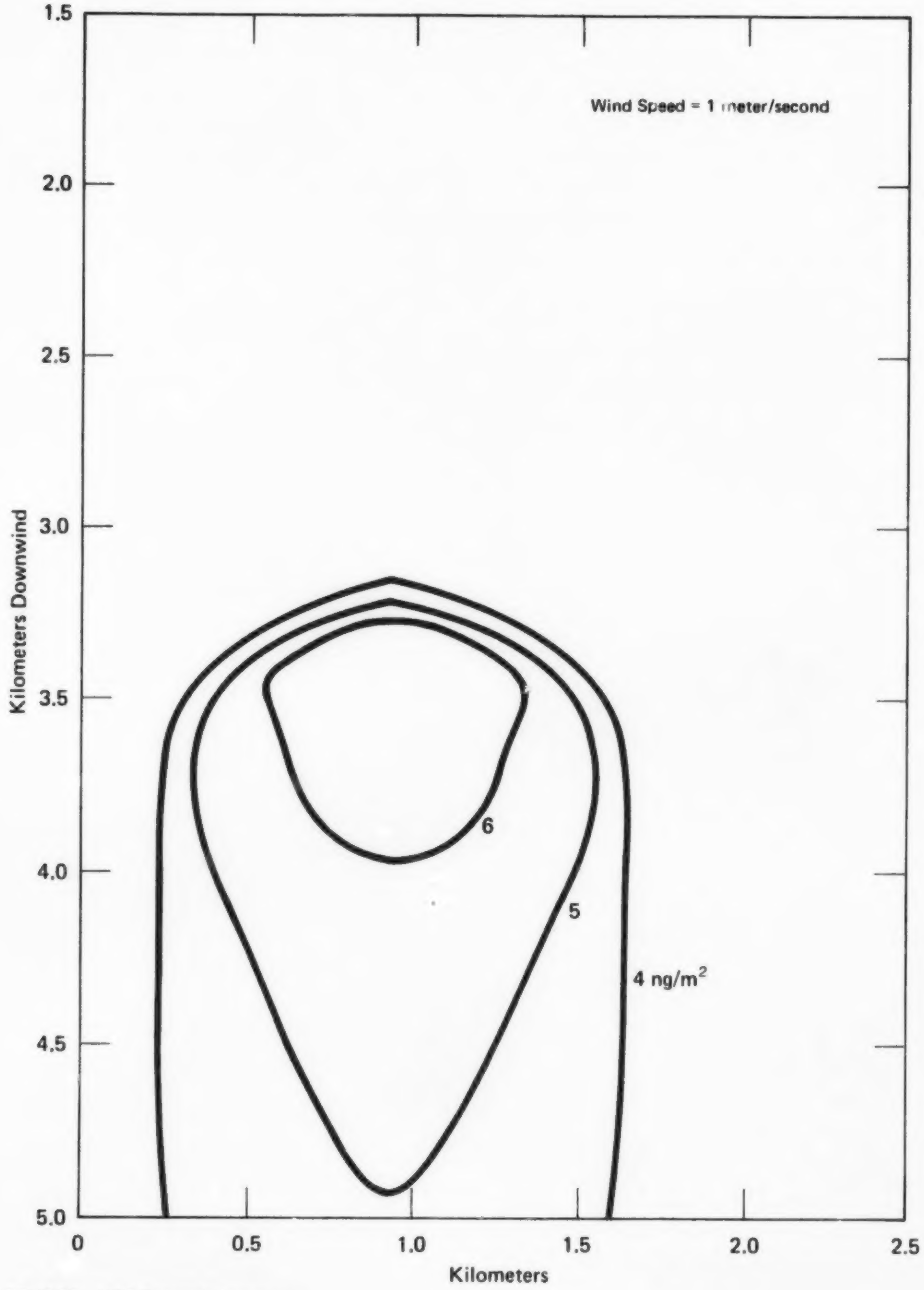
SOURCE: URS Research Company.

Figure E-2 CASE 2: COPPER SMELTER MERCURY VAPOR CONCENTRATION UNDER AVERAGE METEOROLOGICAL CONDITIONS (3-min avg)



SOURCE: URS Research Company.

Figure E-3 CASE 3: COPPER SMELTER MERCURY VAPOR CONCENTRATION UNDER ADVERSE METEOROLOGICAL CONDITIONS (3-minute average)



SOURCE: URS Research Company.

Figure E-4 CASE 4: POWER PLANT MERCURY VAPOR CONCENTRATION UNDER ADVERSE METEOROLOGICAL CONDITIONS (3-minute average)

The mercury vapor concentrations generated from these two point sources are therefore going to be relatively small, even under the most adverse meteorological conditions. Although appreciable quantities of mercury are released from these two sources each year (1,372 kg from the smelter and 589 kg from the power plant in 1973), the emissions occur over a widespread area and are well dispersed before they could pose a hazard to the general population at ground level.

Another concern is the potential buildup of mercury in the soil adjacent to such sources as power plants and smelters. In order to arrive at an estimate of mercury in the soil, various assumptions had to be made:

- The mercury will be found to a soil depth of 10 cm.
- The average density of the soil is 2.5 gm/cm^3.
- Approximately 10 percent of the mercury emitted from an elevated point source is locally deposited within a radius of 10 km.
- Some 80 percent of the deposited mercury remains in the soil.
- The average background soil concentration of mercury is 71 ppb.
- The average life of mercury in soil is 20 years.

Using these relatively gross assumptions, a mercury concentration in soil adjacent to the copper smelter discussed previously was calculated. It was found that the smelter could contribute an additional 111 ppb to existing background. However, by changing the assumptions above to not unreasonable figures, the range of mercury concentrations in soil could be 70 to 890 ppb. Unfortunately, no specific data are available to correlate with these findings, although data points in the general area of the smelter do show elevated levels (>200 ppb).

Based on the information presented above, it appears that copper smelting operations do not pose a health hazard in terms of airborne emissions of mercury. It is very difficult to predict what happens to the mercury once it is released from the stack, as it may adhere to particles and settle out close to the plant, or it may be transported long distances, in which case it becomes part of a regional transport phenomenon. In any case, apparently no hazard to health will be produced as a consequence of air emissions from the smelter studied. Based on these findings and on mercury emissions data from other smelting operations, it seems that no further curtailment of operations, and no new controls, are necessary to reduce mercury emissions.